FOUNTAIN IN PERPETUITY

A historical Examination of Islamic Fountain Design from the Ninth to the Sixteenth Centuries and a Contemporary Interpretation

A thesis submitted in partial fulfilment of the requirements of the University of Wolverhampton School of Art and Design for the degree of Doctor of Philosophy

by

HASSAN M. SHOKRI

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This work or any part thereof has not previously been presented in any form to the University or to any other body whether for the purposes of assessment, publication or for any other purpose (unless previously indicated). Save for any express acknowledgements, references and/or bibliographies cited in the work, I confirm that the intellectual content of the work is the result of my own efforts and of no other person.

Signature:..

Date: 10 – 3 – 2000

Dedication

To whom love and sacrifice are illimitable, without which success is unreachable. The very least that I may offer in return to my beloved mother *Amina* is this humble dedication.

Your son,

Hassan Shokri

According to the recommended ordering of reading the thesis by the 'Viva Examining Board' the preferred chapters order is as follows:

- **Chapter Three**
- **Chapter Four**
- **Chapter Two**
- **Chapter One**
- **Chapter Five**

Contents

Chapter Three

Chapter four

Chapter five

List of Figures

Abstract

This thesis is an examination of the development of fountain design in the work of selected key Muslim engineers, covering the period from the ninth to the sixteenth centuries It first introduces, translates and examines a previously undocumented fifteenth-century manuscript, *Al-Riysala al-Qudsiya fi Amel al-Shadriwaan wal Fisqiya* (The Qudsiya Treatise in Constructing a Cascade and a Fountain), which was discovered by the researcher[1]. Since the manuscript describes a self-operated fountain, the notion of perpetual motion in philosophical and engineering concepts is analysed and presented with an attention to historical accounts, and in the light of practical experiments.

The investigation of the design of eighteen fountains designed at the high point of Islamic civilisation by the renowned engineers: Banu Musa (9th century), al-Jazari (13th century) and Taqi al-Din (16th century) is also characterised by my discovery of two manuscripts[2]. These appear to be originally contemporary copies but have clearly been copied by hand many times with a resulting lack of clarity. The works of these engineers have been studied, in modern times, by prominent Western historians and engineers The evidence for the existence of the 18 fountains takes the form of descriptions and simple diagrams. However, these studies have not been carried out in any depth, and therefore have not resulted in any greater understanding of the nature of such engineering design. In my study, design, manufacture and operation of these fountains are studied as a specialised and specific branch of Islamic engineering Furthermore, a historical understanding of the significant nature of the fountain as a cultural, artistic and engineering product of the Islamic civilisation is brought into focus, and subjected to a practical verification.

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[1] The manuscript is held in King Abd al-Aziz Library, Madina, Saudi Arabia. No. 513/8 Arif Hikmet's collections

[2] The first manuscript is the most recent hand written copy of the work of the 13th cen. Engineer al-Jazari This manuscript is held in Dar al-Kutub, Cairo, Egypt. No. 37 Sina'a Timur. The second one is a fragmented manuscript held in The John Rylands University Library, Manchester, UK. No. Ms 351 [419]

A major aspect of this study has been to interpret these accounts and through practical experiments verify the original claims and present an account through drawings and video-tape of their original working formats. This, together with the translation of the hitherto unrecorded document has allowed me to present fuller and more comprehensible account of Islamic fountain design with special reference to the roles of the identified engineers.

From the experimental work carried out on specific engineering designs, remarkable result are documented which may introduce, as this thesis suggests, a new concept of designing fountain based on the new application of medieval techniques.

The investigative and experimental works in this study have enhanced the statement the researcher has tried to deliver in a form of a contemporary fountain-design. The development of the fountain mechanism as well as the concept of design, the researcher introduces, allows for a fruitful interplay between art, science and particularly engineering, of the past with their counterparts of the present.

Acknowledgement

It would be a long task to express my gratitude to all those who have helped and guided me throughout my research. Nevertheless, I would like to express my personal and unequivocal appreciation to the following people: I am sincerely grateful to Professor Keith Cummings who showed a great interest in the subject of this thesis; this was reflected in full support and encouragement along the period. I also wish to express my appreciation to Dr. Edward Bird who offered me his valuable guidance and did his best to resolve any obstacles that I encountered. I must acknowledge with gratitude, the assistance and the sincere care given to me by John Brierley, who spared no effort to provide me with any possible support. I would like to thank Paul Rattcliff for his kindness and co-operation on discussing technical problem whenever I asked for his help and advice. I remember with gratitude my first guide in the perpetual motion in Islamic engineering, Professor Ahmad Y. al-Hassan, who provided me with his personal document on the subject. My sincere debt is acknowledged with gratitude to Richard Barker (an Engineer and a member of The Fountain Society) who has been generously supportive and always ready to give his advice whenever needed; I must admit that without his help this research would have prolonged. I would also like to express my gratitude to all those I did not mention, who at least have been heartily supportive and have shared my interests.

Introduction

"A person of faith in a mosque is like the sun reflecting in the water"

The establishment of a homogenous Islamic culture in the lands that happened to come into the Islamic fold developed into recognisable architectural, artistic and cultural forms that are characteristically Islamic. With regard to time and space, the uniformity of these characteristics has been the very essence of art and architecture in the Islamic world, while science and engineering have been the catalyst and cultural partner that moulded its structure.

The prime characteristic of Islam, however, is reflected in the definite style of art and architecture that spread over a vast area from China in the east to Spain in the west. This distinctive artistic style and architectural system is associated with the idea and faith of Islam, and in general terms, the revelation of Islam, which constitutes a complete system and way of life. All arts and sciences that flourished in the Islamic world attempted to crystallise the immutable spirit of the Islamic revelation that has conceptualised the structure of the life of Muslims. Art, architecture and engineering have been the tangible and practical manifestations of Islam that is regarded as 'a way of life' rather than a mere reflection of ritual practices.

Although these manifestations appear as apparent facts, values on the other hand constitute the very ground of all facts. However, any attempt to distinguish between facts and values with reference to Islam must be considered ultimately invalid. Therefore, the understanding of most facts cannot be comprehended in isolation of the historical judgements of value with which they are charged. Values, in a scientific and historical sense, are reflections of people's thoughts or beliefs of what it is good, true or beautiful, and the articulation of these thoughts in the form of science and art. Moreover, the importance of values are infinitely more than facts because they are more intimate to and express more directly the comprehensive view of the world, the ultimate ground of the culture, civilisation or time.

Throughout Islamic history, water has been the most distinctive element of representation of these manifestations, which appears as the most common thread in all Islamic art, through which facts and values are delivered. It is reflected in the noblest form of art in Islam, Calligraphy, which has been devoted to glorifying the word of God, the Koran. According to an interpretation by Muslim medieval theologians the Koran is regarded as water. It is the supreme quality of purity in water that is resembled in the transcendental purity of God's words. This is why the calligraphic inscriptions always seem to occupy the most prestigious spot on buildings and architectural artefacts, for instance, the inscription on the outer rim of the Lion-fountain in the Alhambra, or the inscription on the inner circumference of the Blue-mosque's dome in Istanbul. Both secular and religious Islamic buildings, however, have also been characterised by fine and remarkable water-features, the fountain in particular; those that integrate harmoniously with the surrounding sublime calligraphic inscriptions and the intricate interwoven geometric patterns decorating the facades and walls of the buildings.

Parallel to the exquisite water-features, the remarkable achievements in Islamic engineering have always been associated with water, like the magnificent water-clocks of the twelfth-century in Fez and Damascus, the water-wheels (Noria), in Hama (Syria) and the intricate fountains described in a number of engineering volumes. We may gather that water has been a key element in all aspects of Islamic life. The importance of water has been associated with the holiness of ritual practice, the vitality of architecture and the prosperity of engineering development. This use of water is, in a practical sense, a specialised branch of engineering, but one whose outcome was aesthetic, religious, and philosophic in nature.

This is positioned within the religious, aesthetic, architectural, cultural ethos of Islam with its insistence on the totality and centrality of human experience and the way this is derived, in its entirety, from the Koran. The particular central role of the fountain in the mediation between world and spirit cannot be separated from the means by which it is designed, generated, and controlled in terms of its inventive design technology. However any full appreciation of the work of the creative engineers in bringing fountain design to a peak between the ninth and the sixteen centuries is hampered by a lack of information and applied scholarship. Furthermore, not only is primary information scarce, but there is also a lack of accurate interpretations capable of granting insight into their methods and individual genius. It is the principal aim of this thesis to attempt to rectify this, by a variety of means, analytic, experimental and practical, as far as a single study can.

This study has been characterised by the discovery of the new manuscript, *Al-Riysalaa al-Qudsiya fi Amel al-Shadriwaan wal Fisqiya*, The Qudsiya Treatise in Constructing a Cascade and a Fountain, which has not been published in any format before. In fact, this unique manuscript, which I have unearthed[3], is of substantial importance to the history of Islamic design and engineering, since we have no other engineering document that represents fifteenth-century Islam. It describes in detail the construction of the most elaborate water-feature in Islam so-called *Salsabil* which comprises of a cascade and a fountain. This water-feature was interestingly supposed to be operated by a perpetual motion machine. The full-scale reconstruction of the described perpetual machine in this manuscript is not intended to prove its practicality, which is of course impossible, but to examine the interesting complexity of the mechanical ideas applied as well as its design concepts. The complete and faithful translation of the manuscript, on the other hand, is introduced with lucid descriptive text and clear drawings of the construction and operation of the machine to provide a better understanding of the device. Through the investigation of this manuscript this study has aimed to draw some valuable findings that would reshape the predominant image of engineering and design in Islam in the twentieth-century's eye. T. Schiolar wrote in his book 'Roman and Islamic Water-lifting Wheels' that despite the fact those perpetual motion designs bear no significance, the interesting

[3] The manuscript is held in King Abd al-Aziz Library, Madina, Saudi Arabia. No. 513/8 Arif Hikmet's collections.

point is that they tell us about the "attitude" of that period towards such a "mechanical problem"[4].

For the first time this study also reintroduces other perpetual motion machines described by Muslim engineers, the publication of which appeared in 1920 in the only study in any languages by Hans Schmeller in German. The mechanisms of these machines are compared with the mechanism of the machine under investigation and an important conclusion is drawn.

This investigation is also intended to explore some historical background of the nature and the idea of perpetual motion in Islamic engineering and philosophy which may identify the spiritual force behind this quest. This is also supported by an exploration of modern definitions and interpretations of the notion of perpetuity.

As this study is mainly focused on the mechanical engineering of the fountain from the ninth to the sixteenth centuries, I have carried out an exhaustive search looking for manuscripts in various Western and Middle-Eastern libraries. There was a hope that something might be brought to light after long lying in the darkness. Of course such discovery is quite often liable to reveal surprises. In his article ' Muslim Mechanics and Mechanical Appliances' H. Winter states that "indeed, one of the joys of the historian of science who is able to interpret medieval oriental manuscripts is that of finding among many pages of tedious matter some angle of approach, or perhaps a discovery, unknown to the Latin West"[5]. In other words such a discovery may change some prevailing belief among historians of engineering about some mechanical achievements or inventions that have been thought to be unknown at the time of the antecedent civilisations.

Fortunately, this study also has been characterised by the discovery of two engineering manuscripts[6]. The first manuscript, I have unearthed, is the undated and fragmented manuscript in which the fountains designed by the prominent ninth-

[4] Schioler, Thorkild (1973) *Roman and Islamic Water-lifting Wheels*. p. 62.
[5] Winter, H. J. J. (1956) *Muslim Mechanics and Mechanical Appliances*. p. 26.
[6] The first manuscript is the most recent hand written copy of the work of the 13th cen. Engineer al-Jazari, which is held in Dar al-Kutub, Cairo, Egypt. No. 37 Sina'a Timur. The second one is a fragmented manuscript that contains a section on the Banu Musa's fountains. It is held in The John Rylands University Library, Manchester, UK. No. Ms 351 [419].

century engineers known as Banu (sons of) Musa are documented. The second manuscript is a complete work of the thirteenth-century engineer al-Jazari, which was copied in 1914.

In the second Chapter the investigation of the fountain design is restricted to the available edited and published works: 'The Book of Ingenious Devices' by Banu Musa, 'The Book of Knowledge of Ingenious Mechanical Devices' by al-Jazari and 'The Splendid Methods of Spiritual Devices' by Taqi al-Din. These engineering treatises appeared in the ninth, the thirteenth, and the sixteenth centuries respectively. The engineering works of Banu Musa and al-Jazari were edited and annotated in 1979 and 1974 by Donald R. Hill[7]. Later Ahmad Y. al-Hassan[8] published his editing works of Banu Musa in 1981 and al-Jazari in 1979 which are orientated to the people of Arabic knowledge, although he generally followed Hill's steps. The two important manuscripts I have discovered, mentioned earlier, are consulted and used to support my critical comments.

Despite the outstanding edited works of Banu Musa and al-Jazari by Hill and al-Hassan they suffered from two major defects. Firstly, the use of the original descriptive text; and secondly, the poor and basic reproduction of the original drawings as well, which in many cases contributed to a confusing text or a misleading drawing. Therefore, this study is intended to discuss the commentary notes introduce by Hill and al-Hassan on each fountain model and reinterpret them, with references to relevant documents or my experiments are provided. Then each fountain model is presented in the form of a clearer drawing and lucid descriptive text of its construction and operation in order to help the reader to arrive at a better understanding.

In this Chapter I have documented my experimental work on the most interesting fountain-head described by Banu Musa, which puzzled Hill and al-Hassan who could not be confident about its actual mechanism. The twenty-nine experiments I have conducted are designed to clarify its intriguing mechanism through a series of

[7] Dr. Donald R. Hill (died 1994) was an Honorary Research Fellow of University College London, and a professional engineer and Orientalist who wrote several works on Islamic technology. He was the pioneering scholar who introduced the work of Muslim engineers to the Western world in English.
[8] Ahmed Y. al-Hassan is currently a Professor at the Department of Middle Eastern Studies, University of Toronto, Canada.

adjustments and alterations and some fascinating results are revealed. The technical data and the diagrams of the experiments, I have provided, comprise my primary contribution to understanding and developing of this particular fountain-head. Thus from my brief analysis on these experiments I have come to the conclusion that there is a profound potential for further experimentation.

In order to allow the reader to visualise more closely the intriguing behaviour of the water in each experiment as well as the aesthetic quality of each conical or Lily-of-the-valley shape emitted from this fountain-head; all experiments are recorded on a video-tape, which is attached to this thesis. It also incidentally provides concrete evidence of the practical nature of the designs of Banu Musa.

This investigation of the fountain design in the work of the third engineer Taqi al-Din is the first to be carried out in any depth. The only previous publication of this last Muslim engineer and inventor of the sixteenth-century was an offset reproduction of the original manuscript with a monograph on Taqi al-Din issued by A. al-Hassan in 1987 for readers with knowledge of Arabic. Therefore, in like manner, the four fountains described by Taqi al-Din are clearly illustrated and accompanied with lucid descriptive texts of their construction and operation.

This Chapter is concluded by a comparative discussion on the aspects of similarities and differences in terms of the design concepts and engineering ideas adopted by these engineers in their fountains.

Thus, this investigation is framed by a number of points. Firstly, it has attempted to make all documented works on fountains, from the ninth to the sixteenth centuries, more accessible in one single volume in which they are clearly presented. Therefore, people would no longer just appreciate Islamic fountains for their fascinating architectural design, but they will also have an understanding of their equally fascinating engineering designs. Secondly, the experimental work that has been undertaken on a specific fountain-head and mechanism is highly interesting, and is a fertile field for future development. In the case of each of the eighteenth fountains I have as a result of practical experiment been able to provide an interpretation of the original drawings. Finally, this study has attempted to place the work of each identified engineer within the context of engineering and design, and to assess each individual contribution and importance.

Chapter three in this study is concerned with the cultural characteristics that define the significance of water to Muslims from a religious, philosophical and artistic perspective. The objective of this introductory presentation, however, is to bring into focus the philosophy of water within the religious and cultural contexts in Islam and to give a better understanding and appreciation of the significance of the life and soul-giving substance, water, in the life of Muslims. Also, it is to explore some mystic and poetic reflections on the enchanting spirit of water, the perception and appreciation of its smell and colour and the jubilant charms over its movements. This exploration outlines the immutable connection between the spiritual and physical worlds that revolve around the sublime nature of water as an agent of meditation and purification for the body and the soul in the daily life of Muslims, which is reflected in the design and engineering of these remarkable fountains.

The following point of discussion in this Chapter is the cosmological aesthetics of the fountain in Islam, which has not been studied prior to this thesis. Therefore the researcher has tried to bring into focus the importance of this characteristics perception of the fountain in Islamic culture and to establish the concept 'Cosmo-aesthetics of the fountain in Islam'. This concept has been drawn from a study of the theories and philosophies that have contextualized and formed Islamic art, which imbued religious values, ethical qualities, cultural traditions, cosmic law, principles of science and other domains of knowledge with a sense of order, coherence and unity; these are in fact the formative components of the overriding aesthetics from an Islamic perspective. Taking the fountain as a study case, this thesis shows how symbolic qualities of aesthetic in any form of art are often conveyed by abstract symbols. This symbolism, however, represents the very nature of the act of aesthetic perception in Islam, through which an image is charged with strong spiritual values, aesthetic qualities, symbolic meanings, and cosmological connotations. Particularly so in a culture that proscribes direct literal representation.

The fountain in the context of Islamic architecture is the third point this Chapter discusses, in which a stress is put on the typology of the fountain. This was not discussed in any depth in previous studies. Furthermore, this study has clarified the principles of fountain design in Islam in which the interlocking relationship between symbolism, functionalism, and formalism reinforces the predominant Islamic philosophy of unity in all arts and sciences as opposed to the modern Western theory 'form follows function'. A light is thrown on the poetic of water architecture in Islam, and finally this is been supported by a report of an interesting modern survey to measure the perception and appreciation of the fountain in outdoor and indoor environment.

I have concluded this chapter by listing the three distinctive water-features known in Islamic architecture: *Sabil* (Drinking-fountain), *Salsabil* (comprises a cascade, a fountain, a channel and a pool) and *Fawaara* (Fountain). An introduction to the nature and the origin of each type and its principle of construction is given, this accompanied with an illustration of each example. Previous studies have not paid attention to similar collective presentation of these water-features, so in this study reader is offered a historical background on the specific water-features that characterise Islamic architecture from Central Asia to the Atlantic.

As far as the engineering of the fountain is concerned the fourth Chapter discusses the role of engineering in Islamic culture. However, to study the role of engineering in Islam, one must recognise philosophy as a keystone of historical understanding. Any attempt, however, to separate Islamic science and philosophy cannot be undertaken without doing violence to each of them. Muhsin Mahdi writes that "Science is possible and even necessary, but it is essentially the product a manifestation (in the form of self-consciousness, ideas and ideals, as well as practical needs) of a specific historical setting"[9].

On the basis of this realistic interpretation of how science and philosophy have been perceived and comprehended in Islam, this Chapter, therefore, is devoted to exploring Islamic engineering in relation to its underlying philosophy. This study

[9] Mahdi, Muhsin (1996) *Approach to History of Arabic Science*. p. 1040.

introduces first historical accounts of the transmission process of sciences and technology from the existing cultures absorbed into Islam, form example Greek and Persian. It also illustrates how Muslims have perceived and responded to the heritage of previous civilisations through the spirit of the Islamic revelation. Finally, the realistic interpretation of science from an Islamic perspective, which based on the synergetic classification of arts and sciences is highlighted. This in return brings forth the notion of the sacredness of science and art in Islam.

However, the study of Islamic engineering is not as easy as it may seems since the limitation of references and material on this subject has handicapped the researcher, this is due to the fact that Islamic science and engineering has received scarcely any attention. Furthermore, there is no satisfactory research in any branch of engineering and technology in Islam. In 1986 UNESCO undertook an initiative to address the shortage of adequate references and materials concerned with the contribution of Muslim civilisation to the modern world. The result was the first published book dealing with Islamic technology, 'Islamic Technology: An Illustrated History'. In the introduction of this short book which was composed by two prominent engineers, Donald R. Hill and Ahmad Y. al-Hassan, they affirmed that to the present time no single coherent work has been written on Islamic technology, for it seems that researchers have been restricted by insufficient published work. There is no chapter devoted to Islamic engineering in any of the leading publications on the history of technology, and where it is mentioned, the author shows little affection for Islamic civilisation[10].

However, in this Chapter I have reviewed various definitions of mechanical engineering in Islamic sources, bringing also the Western idea of Islamic technology into focus. Through these focal points, the thesis is intended to throw light upon the tradition of mechanical engineering in Islam, trying to draw a conclusion of its actual meaning and definition of its nature and philosophy. From the investigation of the different aspects of fountain design the current work is unique in its approaches and contents since there is no such documentation either in Arabic or English that has

[10] Al-Hassan, Ahmed & Hill, Donald (1986) *Islamic Technology: an Illustrated History*. p. xiv.

been dedicated solely to the fountains and its historical, aesthetic, and engineering significance.

In Chapter five, I have been able to transform the amalgam of experiences and practices I have been through my investigation of fountain design into a personal statement. The vocabularies of this statement form the outlines of a fountain design that is intended to reflect the spirit of the contemporary life and at the same time manifests the Islamic cultural background. The simple and abstract form of the design is virtually contemporary. The combination of the outline of the fountain body and the outline of the produced emissions, however, convey the aesthetic, spiritual and philosophical messages. This hybrid composition of these messages would echo with one's reflections and mediations. The Cosmic-Fountain, as I have called it, which is intended to occupy the heart of an enclosed courtyard also communicates the idea of the symbolic link between the terrestrial and the celestial by which man would seek refuge to contemplate upon.

Equally important is the engineering design of the device attached to the fountain which derived from the unique multi-valve control, which is mechanically operated was designed by Banu Musa in the ninth-century. The intention of this study has been to design and produce a compact water-control that perfectly feeds a maximum number of different fountain-heads in succession adopting the principle Banu Musa used in their design. Therefore, the development of this multi-valve control is undertaken in this study and a full documentation of the experiments and their technical drawing are clearly presented. In addition, a video recording of experiments is provided, so reader can watch more closely the fascinating results of this device and the supreme practicality of one thousand years technology.

However, it is clear that given this understanding of the principles behind the work of Banu Musa, that further experiments would yield many other variants. The limits of this study however must leave this for future development.

The conclusion that has been drawn from this study represents the significance of the fountain, as an outstanding manifestation of the culture and the spirit of the

Islamic civilisation. Furthermore, this study is intended to emphasise the true knowledge of a civilisation and its production of art and engineering that cannot be attained by neglecting the science of historical understanding. This is why the thesis has tried to constitute a frame-work of historical understanding of art and engineering of the fountain design in Islam before introducing the remarkable designs of fountain produced in the renaissance period of Islam. These evidentiary findings will help in the process of repositioning the status of Islamic design and engineering in history of world civilisations.

Finally, as facts and values of the past and the present, which hinge on understanding the manifestations of human production and life in relation to the comprehensive views on which they are based; the researcher has been able to introduce his personal statement of fountain design.

- The Manuscript.
- The Perpetual Fountain.
- Examination of the Perpetual Fountain's Machine.
- Translation of the Manuscript.

The Manuscript.

The discovery of the present manuscript, Al-Rissalla al-Qudsyia fi Amel al-Shadriwaan wal-Fisqiya (The Qudsyia Treatise on Constructing a Cascade and a Fountain), which I have unearthed during preliminary research, casts a substantial light on the engineering domain in Islamic history. Therefore, the investigation of this manuscript is intended to throw light on its significance that lies not merely in the mechanical device and the fountain it describes, but also on the significance that lies in its representation of a very important period in Islamic civilisation since we have no engineering documentation that covers the tradition of Islamic engineering during the Mamluks dynasty (1250-1517AD).

The manuscript is an acquisition of King Abd al-Aziz Library, Madina, Saudi Arabia; and is listed under Arif Hikmat's collections No. 8/513 . It contains 39 folios (two opposite pages) of medium size and has a ruler of twenty lines; it suffers no damages and stands in perfect condition. The first eight folios are divided into three chapters that are dedicated to describe the construction of a perpetual motion machine and the construction of a cascade and a fountain, which are connected to the machine. The fourth chapter occupies the next twenty-seven folios, which describe the construction of a water-clock, which is connected to the machine, and also describes a set of automated figures, which are arranged between the fountain and the cascade. The last four folios comprise the second treatise that describes a perpetual water-lifting device. However, the description of this device seems incomplete since the author of the manuscript claims in the conclusion that a supplementary treatise will follow this manuscript in order to provide a complete description of other component parts used in this machine.

This manuscript that I have discovered bears no reference to the engineer who wrote it, except a brief biographical account of him in the introduction he himself provides, telling us where he lived and where he composed the treatise. He was brought up in Cairo where he seemed to have spent most of his life; he moved to Jerusalem for some reason, where he composed this manuscript. He also refers to his patron Prince Murjaan and the prominent thirteenth-century engineer al-Jazari who, as he claims, were his prime source of inspiration. It is very likely that the manuscript was composed some time before 895AH/1489AD as this date appears in the second treatise in this manuscript, which deals with the water-lifting device.

Just as we know almost nothing about the author, likewise we know little about the patron to whom the engineer referred, Prince Murjaan. A short biographical record about Prince Murjaan is given in the book *Al-Daw'a al-Laamyi'a*, (The Bright Light, of al-Sakhaawi)[1], in which he writes: "Murjaan al-A'shrafi Bursby, the founder of *saqiya*, water-wheels, who is known as Sutma'a, worked in mathematics, astronomy, geometry, and time-keeping, ... He died at the age of ninety four years, leaving behind a sizeable collection of books and other things"[2].

The only information the manuscript provides us with is the name of the copyist and the date of the copy, which was copied in 936AH/1529AD, although we could trace nothing about the copyist Abd al-Qadir Musa al-Khatiab, a timekeeper of the Great Mosque in Damascus, who introduced himself in the conclusion of the manuscript. However, we are informed about the person to whom the manuscript was dedicated, he who commissioned it, the renowned scholar Ghars al-Din Khaliel al-Halabi. The copyist's master, Ghars al-Din Khaliel al-Halabi, however, was privileged with a good biographical record. The biographical dictionary *Al-Kawaakib al-saa'ira bi-a'yyan al-mi'a al-aashira* (Biographies of Eminent Personalities of the Tenth Century) by Najm al-Din al-ghazzi tells us about his full name and describes briefly his scholarly life. A lot more about him is documented in *I'llam al-Nuballa' bi-tariykh Halab al-Shahba* (Informing the Nobles of the History about the Glamorous Aleppo) of Mohammed Raghib al-Halabi, which gives references to other biographical references on this celebrity. The following is a brief extract of what is

[1] Shams al-Din al-Sakhaawi is a prominent biographer and theologian who lived in the fifteenth-century. He wrote more than two hundreds books, the most important of which is this book *Al-Daw'a al-Laamyi'a*

[2] *Ibid.* p.153.

most relevant, M. al-Halabi writes: " Khaliel bin Ahmad al-Shaikh Ghars al-Din Ibn al-Shaikh Shibab al-Din, is originally from Hums, and was born in Aleppo, ... (he studied) mathematics, time-keeping, astronomy, science of numbers, music, and medicine. ... He collected numerous rare books, fine time-keeping devices, and spent a fortune on alchemy. ... He passed away in 971 AH, may God bless his soul"[3]. Despite the fact that I could not trace any reference for the copyist, we may gather that the copyist was a knowledgeable person in the field of engineering, since we know that he held a time-keeping profession, which means he had been responsible for the complex water-clock built in the Great Mosque in Damascus.

In the course of this, it seems that we have been less informed about the author of the manuscript, yet from these many references we can grasp the state of the scientific life at the period of the manuscript, the fifteenth-century. This is gained from the biographical information about people associated with the manuscript's author. Admitting to speculation, but referring the information gathered, there are grounds for believing that this manuscript, in some respect, was well circulated, although we have no other copy in our hands for the time being. Nevertheless, we may infer some historical facts to reinforce these assumptions. From the biographical accounts of the author's patron and the copyist's master we are left in no doubt that the interest in the 'Art of Mechanical Devices' among figures from the religious establishment and the ruling elite was wide spread. This can be realised from the prosperous life during the Mamluks dynasty (1250-1517), which is perceived from the state of the surviving magnificent architecture and from the scientific documents, which have come down to us. Also we are informed, as far as engineering is concerned, that documents representing different period were in circulation as the author of the manuscript tells us that he accessed and studied the book of his predecessor the thirteenth-century prominent engineer Al-Jazari. In his introduction

[3] For more biographical information see the book *Ia'llam al-Nuballa'a bi-tariykh Halab al-Shahba'a* by Mohammed Raghub al-Halabi. p. 57-60.

the author highly praises his predecessor al-Jazari and also he proudly indicates his own innovative work, he writes:

> "...*idea was initially devised by the master of the era, the most innovative Immad al-Din Ismail Ibn al-Razzaz al-Jazari. From his book I have benefited in this art, I mean the Art of the Ingenious Mechanical Devices, al-Hiyal, and God has enlightened me with unprecedented ideas*"[4]

This statement also tells us that the author was a highly professional engineer and we may assume as well that his work enjoyed a good reputation at the time, although we possess no reference to reinforce such an assumption. But the span between the date of composing the manuscript and the date of copying it, which stretches over forty years provide us with an indication about the recognition of this manuscript as well as the author. This can be deduced from two important points. Firstly, the author must have occupied a good position under the patronage of his master Prince Murjaan who was a scholar and professional engineer. Secondly, the manuscript must have been well circulated among scholars and engineers, as we are informed that the copy we possess, was copied in Damascus when the author wrote it in Jerusalem.

On these accounts, It may seem illogical for a skilful engineer to dedicate an engineering treatise to the design of a perpetual-motion machine, in other words to contrive what he must clearly have known to be impossible. In fact the obsession with perpetual motion has along history that stretches up to the twentieth-century. As in Islam, in the West some prominent engineers have dealt with idea of perpetual motion; however, this has not undermined their status as recognised engineers; and is widely discussed in Chapter five. Although, there is some truth in the common belief that engineers wrote such engineering treatises on perpetual motion just to please and amuse their patrons and commissioners, the quest of perpetuity in Islamic engineering was more spiritually motivated than politically driven. Evidence of this can be drawn

[4] See the first page of the translated manuscript in this Chapter, p 72.

from the engineering work of the renowned engineers Banu Musa, al-Jazari and Taqi al-Din[5] whose documents are devoid from any design of perpetual motion, although they were courtly engineers and had very tight connections with the ruling elite.

In fact, the philosophy that stands behind this quest may be associated with the permeating concept that governs all aspects in Islam, which is based on the principle of origin and centre. Obviously, this is reflected in all art, architecture and science, in which the manifestation of principle that every thing that comes out from an origin must lead back to it[6]. This philosophy can be traced in the perpetually operated fountains designed by Banu Musa, al-Jazari and Taqi al-Din, in which water that is diverted from a river or a stream to operate a fountain is driven back to its source. The design of the perpetual fountain in the manuscript under investigation is, in some respect, a continuity of this philosophy, although it takes a different engineering approach, in which the engineer attempted to design a closed system perpetual-motion machine to operate the fountain. This ambitious design was more likely an attempt to overcome the absence of a nearby running water source to operate the fountain continuously and also to satisfy the spiritual quest for perpetuity. So we may gather that this combination of desires and needs was the real force behind the engineer's endeavour to contrive a perpetual-motion machine in which he employed his skill and knowledge to introduce a complex of mechanical ideas.

Despite the fact that this manuscript deals with the impossible engineering principle, perpetual motion, nevertheless it paradoxically provides us with a great deal of information that is substantially important regarding the history of Islamic engineering, in general, and fountain design, in particular. The following points will throw light on each important aspect of this manuscript:

1. This manuscript is the only engineering document that represents the fifteenth-century Islam. Also it is the only engineering work that introduce the Mamluks

[5] The work of these engineers is widely investigated in Chapter two.
[6] This philosophy is fully explained in Chapter three.

dynasty, although we possess some documents that deal with the warfare of that period.

2. There is no complete manuscript that describes in detail the construction of a perpetual-motion machine prior to this one. All other manuscripts suffer serious defects, which have made them extremely difficult to understand. This is discussed later in this chapter.
3. For the first time in the terminology of medieval Islamic engineering we come across term and definition of this mechanism that is parallel to the modern definition. All previous manuscripts that contain a description of a perpetual machine[7] contain the common term "Wheels that turn by themselves" as a descriptive term of this principle. Whereas in this manuscript the author was more precise and clear in naming this mechanism and defining it, which is believed to exist just in Western sources. The author writes in his introduction: "*I wrote down a draft on constructing a fountain and a cascade of perpetual-motion type, which requires no external water source out of itself and its mechanical parts*"[8]. This statement has provided us with the modern term 'perpetual motion' and its definition as a mechanism that requires no external source to move it.
4. The manuscript describes for the first time the most elaborate water-feature in Islamic architecture so-called *Salsabil*, which consists of a cascade and a fountain, although the manuscript does not mention it by name. This water-feature is introduced in Chapter three.
5. The design of the perpetual machine shows a radical departure from previous mechanisms appeared in the work of other engineers; the idea of which is based on complex mechanical concepts, exploiting levering and falling-weight mechanisms, and using a uniquely designed wheel; this machine is investigated and tested in this Chapter. The engineer seems to be very confident about the practicability of this intricate design. He, in fact, referred to a previous model of the same mechanical concept of the perpetual motion type that was devised by him, although he did not tell us how successful it was. Also he provided us with a

[7] Hans Schmeller and Thorkild Schioler investigated these machines; their works are discussed later in this Chapter.
[8] See the manuscript in the translation provided in this Chapter, p. 72.

number of assumptions about alternative mechanical solutions to overcome certain problems or to increase the efficiency of the machine. Yet this machine, as the engineer claimed, has been a radical development on the previous one, we may gather that he neither tested this machine or the previous one. Despite the fact that the engineer has demonstrated such confidence in the practicality of this design, he, on the other hand, did not try to make the reader believe that he really made and tested this machine. This is why he expressed his wishes to see the machine in working order when he wrote: "*By the blessings of God this machine will appear in a strong state and perfect performance as an ideal concept in such good design*"[9]. In contrast, in the other manuscripts the authors tried to give the impression that their machines are constructed and working.

6. Unlike other Muslim engineers, Banu Musa, al-Jazari and Taqi al-Din, the author of this manuscript has shown a profound care in giving full measurements, information on materials and a very precise detailed description of the machine's parts. Nevertheless the engineer lacked the skill of technical drawing, and this is why, as we may infer, he elaborated verbally on the mechanical description of the machine.
7. The engineer is keen to explain briefly the physics of some mechanical concepts that were ignored in the work of the other engineers. For example, he writes: "*Then the vessel unavoidably becomes heavier and is adequate to exert heaviness [force]; this because it is set on a circumference of a circle that is four times bigger than the circle of the falling-weight* "[10]. It is very clear that the engineer was quite knowledgeable in mechanics and physics, which can also be seen in his distinct interest in rather complex machines. Yet, it is safe to say that there is an application of logic in the mechanical concepts on which the engineer had based his design of perpetual motion, also his designs seem to be more convincing than the other mechanisms described by other engineers, which I will discuss later in this chapter.

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[9] See the translation of the manuscript, p. 73.
[10] See the translation of the manuscript p. 80.

8. The idea of portability is a new engineering concept, which is for the first time introduced in this manuscript. This particular design concept is not found in the previous or succeeding works of Muslim engineers. The engineer in this manuscript gives a very elaborate explanation of the dismantling and assembling techniques of the fountain and its machine. This not only sets his work apart from his predecessors and successors but also parallels the work of designers and engineers of modern era.
9. Miniaturisation is another new design concept the engineer introduces for the first time in the history of Islamic engineering, which again has no parallel in the work of other Muslim engineers. This miniaturisation was, as we may gather, a result of experimental problem solving. The perpetual fountain is intended to be built in a restricted space, this is why the engineer introduced his miniature design.
10. The engineer has introduced a water-clock that he describes it an "Astronomical device". The interesting feature is the idea to incorporate a water-clock with the fountain. This small water-clock according to his claim has been developed significantly from the one designed by al-Jazari[11], and he proudly attributes this innovative development to himself. In fact this water-clock needs to be investigated and examined, which is beyond the scope of this study. On account of all these indications we find ourselves left with strong evidence that the engineer was endowed with the skills and experiences and was aware of the work of his predecessors and contemporaries. He was also clearly the type of engineer who relied on experimental work in developing and making his own designs.
11. The author also seems to have a deep knowledge of automata. He describes in the introduction a number of automated figures, which are to be arranged between the fountain and the cascade. He acknowledges the works of al-Jazari on automata, he who was his source of inspiration, although he claims a significant development in his work. Nevertheless, we find no technical details about how these figures, how they were constructed and what kind of development they underwent. We may

[11] al-Jazari designed number of water-clocks which are regarded as the most profound achievement of the thirteenth-century Islamic engineering. Donald Hill investigated this subject in his book '*Arabic water-clocks* (1986)

deem that there must be another treatise in which such details were included, for which we have no reference.

12. The artistic and aesthetic aspects were also shown in the design. The engineer, or the designer, was aware of the pleasure and comfort that can be gained from watching the movement of the mechanical parts by concealing certain parts of the machine to make it more appealing and draw the attention to the spectator. He writes: "*because it is this sort of things, which is a ravish to the eye and such a pleasure to watch*"[12]. In order to enhance the aesthetic quality of the fountain the designer also sought every noble material for his miniature architectural water-feature to enhance its aesthetic quality. The water gently cascading from the marble slab, ***Shadriwaan***, which is coated with gold-leaf, strikes the eye with uneven sparkles of water, especially when it is exposed to the beam of sun-rays. To create a full scenario of water-architecture, the designer set a miniature pavilion above the fountain, which also is intended to increase the electric sound of water from the dome to the ear.
13. As far as the aesthetics of fountain design is concerned, the engineer has introduced a rather neat design solution. He attached a cascade to one of the machine walls. In doing this the engineer turned the machine housing (box) from being an obstacle to the eye to something to live in harmony with the architectural setting of the place. The cascade is made of a gold-coated marble slab resting diagonally on the machine's wall. On either side of this slab, two marble or fine-wood columns are arranged to create that palatial scenery. Above this marble a number of cast-animal-heads are fixed to the wall from which the water is spouting from their mouths to descend down and cascade onto the golden surface of the marble, then to find its way into a small tank at the other end. This compound design of the cascade, *Shadriwaan*, and the fountain, *Fysqiya*, is unique and substantially important. It documents for the first time a detailed description of the design and construction of a *Salsabil*, although it is much smaller than the original one. But we have no such document that describes very clearly this unique water-feature. (See figure 1).

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[12] See the translation of the manuscript p. 47.

14. Apart from the engineering ability, the engineer surprisingly shows us an artistic creativity and deep aesthetic quality in his design. The automated figures are set not to celebrate any significance of the figures in their own right, but to manifest the artistic and aesthetic dimensions of the their mechanical movement. Although the presence of such figures is not of preference in Islam or more precisely is prohibited, we find a few examples of such designs that were adopted in Islamic art and architecture. The fact is that there is in Islam a reluctance to represent any living things[13].

As the fountain is the very specific interest of this thesis, I will concentrate here on just the eight folios of the treatise which describes the construction of the perpetual fountain and its machinery. In order to investigate and examine this fountain a faithful translation of the treatise became vitally important. Although it did look a reasonable task to do in the beginning, the complete absence of drawings and the mere verbal description of a complicated machine made it not an easy task to accomplish as previously thought. Imagination has been the key concept to clarify the picture of fountain as the engineer introduces it, despite the fact that some confusing

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[13] According to prophetic tradition, on the Day of Judgement the punishment of hell will be meted out to the figure fashioner, and he will be called upon to breathe life into the forms that he has fashioned; but he can not breathe life into anything. So as Islam does not clothe its Deity in any mythological/ anthropomorphic garb, the art of Islam, on the other hand, was bound not to accept the representational imagery and least of all a humanistic one. The denial of idols in Islam, and even more strictly their destruction, is in fact the practise of the renewal of the Abrahamic monotheism, and it is an interpretation of the fundamental testimony of Islam that "There is no divinity apart from God". So this denial, whether it appears real or virtual, tends to become generalised. The representation of the holy people in particular, like prophets and saints, is strictly rejected in Islam; that is not just because such images could become objects of idolatrous cult, but also because it drives out the respect of what is inimitable in them. Aniconism, however, by no means degrades the quality of the ambience of man, as far as art is concerned. In his article '*The Void in Islamic Art*' Titus Burckhardt (1984) writes that by excluding every image, aniconism, on the contrary, through the void it creates could invite man to fix his mind on a fact outside himself and to project his soul in an 'individualising' form. (p. 80)

In this respect the use of abstract vehicles of representation are much favoured in Islamic art. This abstract representation ensnares the mind and introduces it into a rather vivid imaginary world, in which the mental symbols dissolve, just as the contemplation of a stream of water descending downhill or of a leaf trembling in the wind can detach the consciousness from its inward "idols". Igarshi Hitoshi (1987) introduces a reflection on iconism in his article '*A Theory of Creation and Beauty in the Qur'an*'. His analytical observation on the figurative representation in the modern centuries has left him with great belief that the process of the reification of God or the deification of things is quite noticeable. He writes that "the case was true not only to the birth and growth of capitalism or the realisation of industrial society, but to the kingdom of art and aesthetics, where a work of art, which was once an *Opus dei* has risen to the level of *Deus rei* or a Divine entity".(p. 47) words in some parts are unhelpful. In my translation I have tried to be as faithful as I can, therefore it would not be, in some respects, that comfortable for the reader to read through for a straightforward understanding of the construction of the fountain and its device. This is why the translation will be followed by my interpretation in order to explain every intricate part of the machine accompanied by very clear and detailed drawings in order to help the reader to arrive at an understanding of the construction of the fountain and its mechanism.

In order to gain a full understanding of the machine, I have also reconstructed a full-scale model and undertaken experimental work. My intention in carrying out these experiments has not been to prove the practicality of the mechanism, which is undoubtedly impossible, but the intention has been to examine each component part of the machine in relation of the other. This is to clarify the application of the complicated mechanical concepts, and most importantly to throw light on the skill and the ability of the engineer to design such an intricate machine. In my experiments I have allowed for a series of adjustments and modifications in order to measure the best performance of each component part, and which therefore illustrates the principles the engineer based his design upon. Despite the absolute impracticality of the machine, it has shown genuine artistic and engineering ideas, which is much closer to the principle of perpetuity and much superior to the other machines that introduced by the other engineers; this is discussed later in this Chapter.

So the following will be the full translation of the treatise in which I have included the only two crude and useless drawing as they occurred in the original text. My interpretation of the fountain and its machine is then to follow, in which I must point out that there is no reference to measurement or material used, despite the fact that the engineer has provided us with full measurement and material information. The reason for excluding reference to measurement and material is because since the fountain has no significance as far as the mechanism of perpetual motion is concerned such information seems unnecessary. However, the reader may consult the translation in which reference to some measurement unit are footnoted, also the reader may refer to table of measures and weights used by Muslim engineers in the next Chapter under al-Jazari. These measurements are similar to the ones occurred in this manuscript.

The Perpetual Fountain and its Machinery

- **Construction of the perpetual fountain**

Here I will describe the construction of the machine, following this with an explanation of the proposed mechanism by which the fountain and the cascade were operated. The reader may refer to the plan drawing of the fountain and its machine, figure (1), to obtain a clear vision of the idea utilised by the engineer. I have avoided the terms used by the engineer, which are quite long ones; instead I will introduce more convenient modern terms for the machine parts. The machine encompasses three main tanks, two wheels, a lever, and falling weight. My description of each part of the machine will be just bound to its construction and its function within the machine, so no details of the dimensions or the materials used will be given unless necessary. Also no detailed description on the construction of the *Shadriwaan* will be included, although I have presented it very clearly in the drawing provided.

- The Supply-tank (t1):

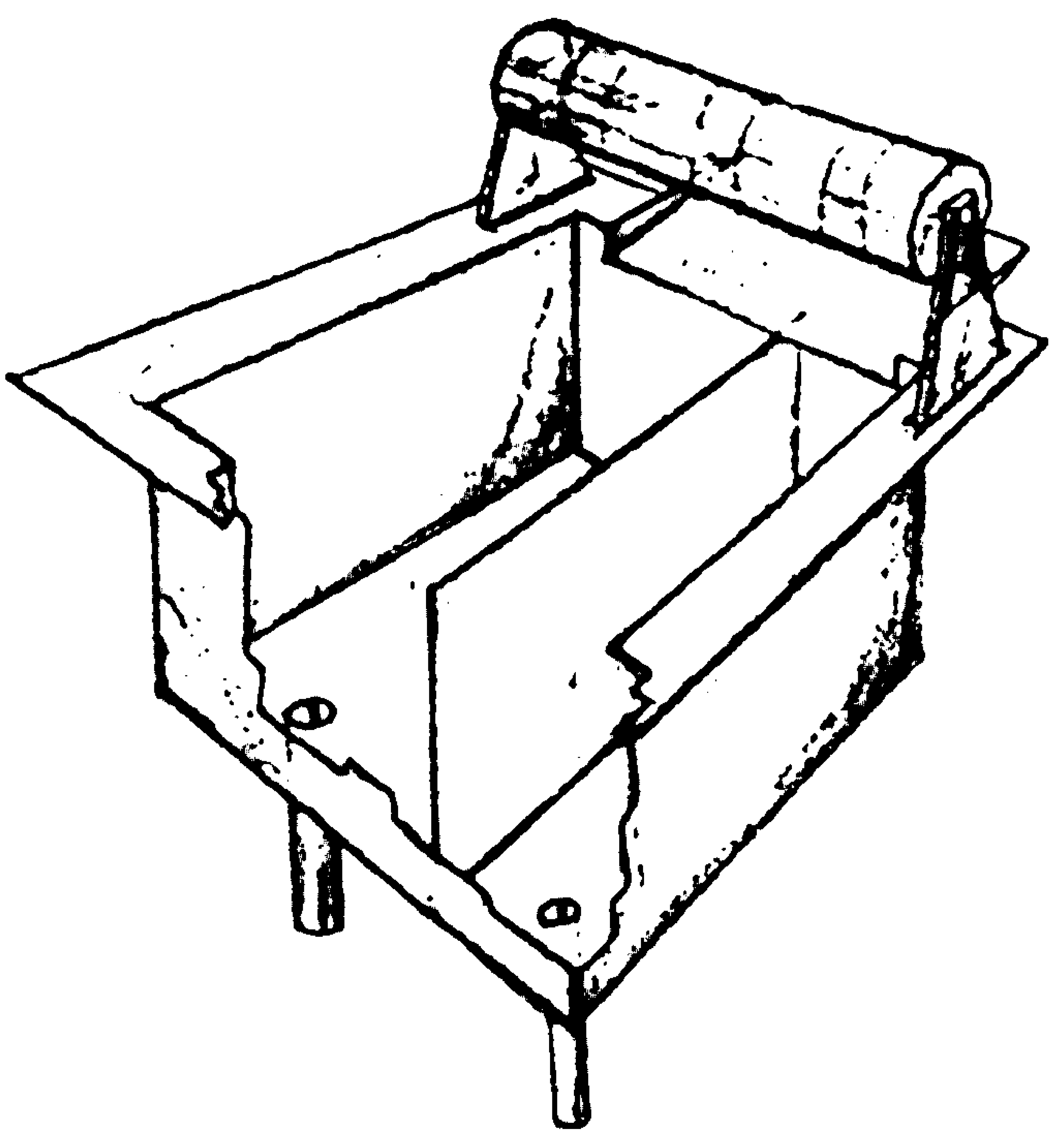
  This tank is erected on the floor of the machine housing. Two pipes (h, d) are branched from this tank; the first one is linked to the basin of the fountain while the other is connected to the sub-tank (t3). So the water in this tank maintains the same level as the water in the basin and the sub-tank. This tank is divided into two sections; the lower one is twice as the size of the upper one, which is enough for a complete immersion of the delivery-pots (b1, b2). A hole on the dividing plate connects the two sections of the tank. Before setting the machine in motion this tank is to be filled with water alongside the sub-tank and the fountain basin.

- The Sub-tank (t3):

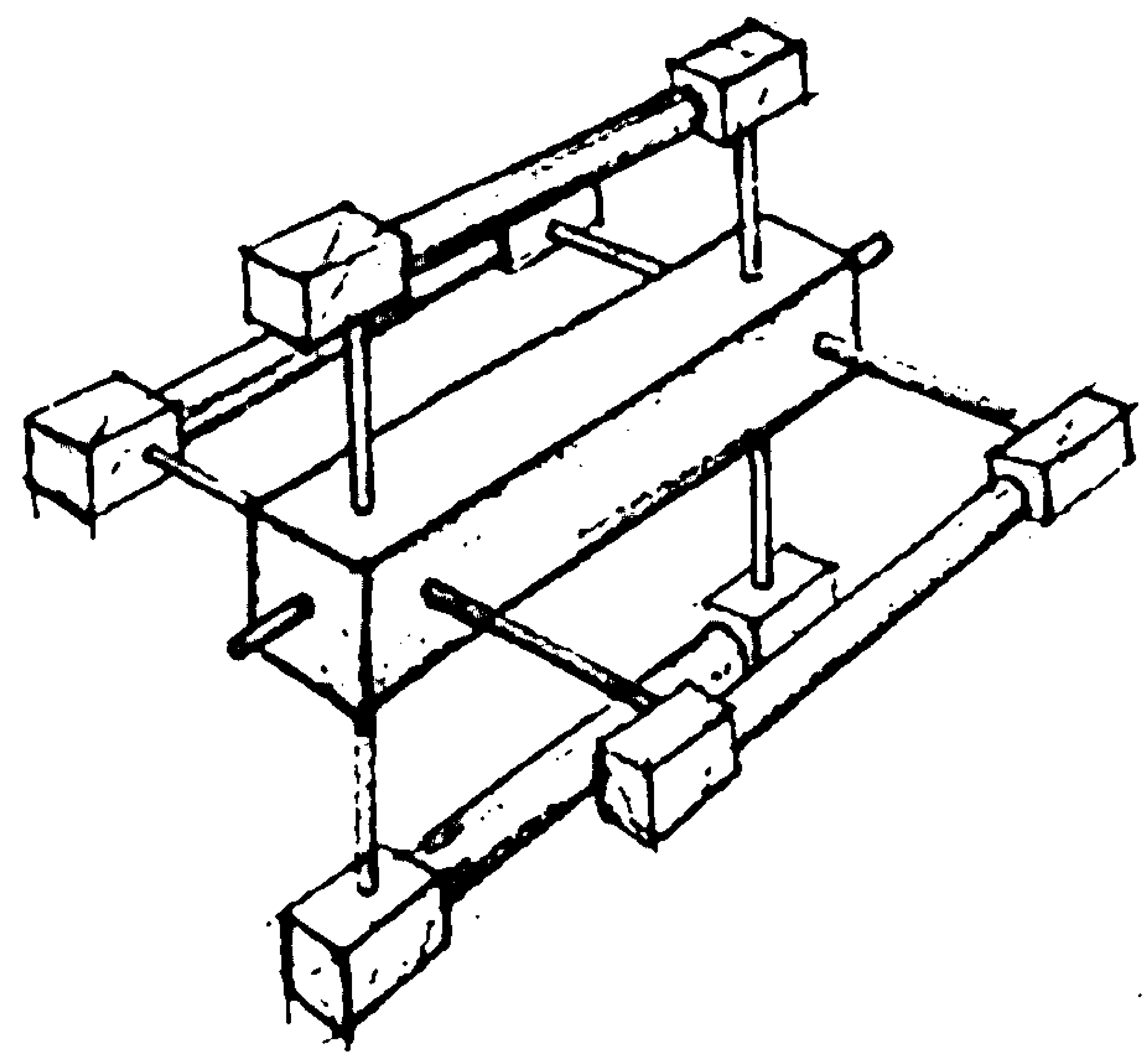
  This tank is smaller than the supply-tank but the same height. It is also erected on the floor of the machine housing. It is set to receive the water from the lever-vessel (v). Pipe (z) is branched close to the top of the tank and linked to the animal-heads on the outer wall of the machine under which the Shadriwaan (s) is erected.

- The Feeding-tank (t2):

  The tank is located above the supply-tank and also above the altitude of the fountain-head. It is divided into two sections, one is a third of the size of the other. From the bottom of the small section, a small pipe (m) is branched and comes in line with the mouth of the lever-vessel (v) into which it pours out the water. A long pipe (n) is connected to the bottom of the large section and its other end terminates at the fountain-head. Around the rim of the tank a platform is attached on which the pots-wheel (w2) is erected.

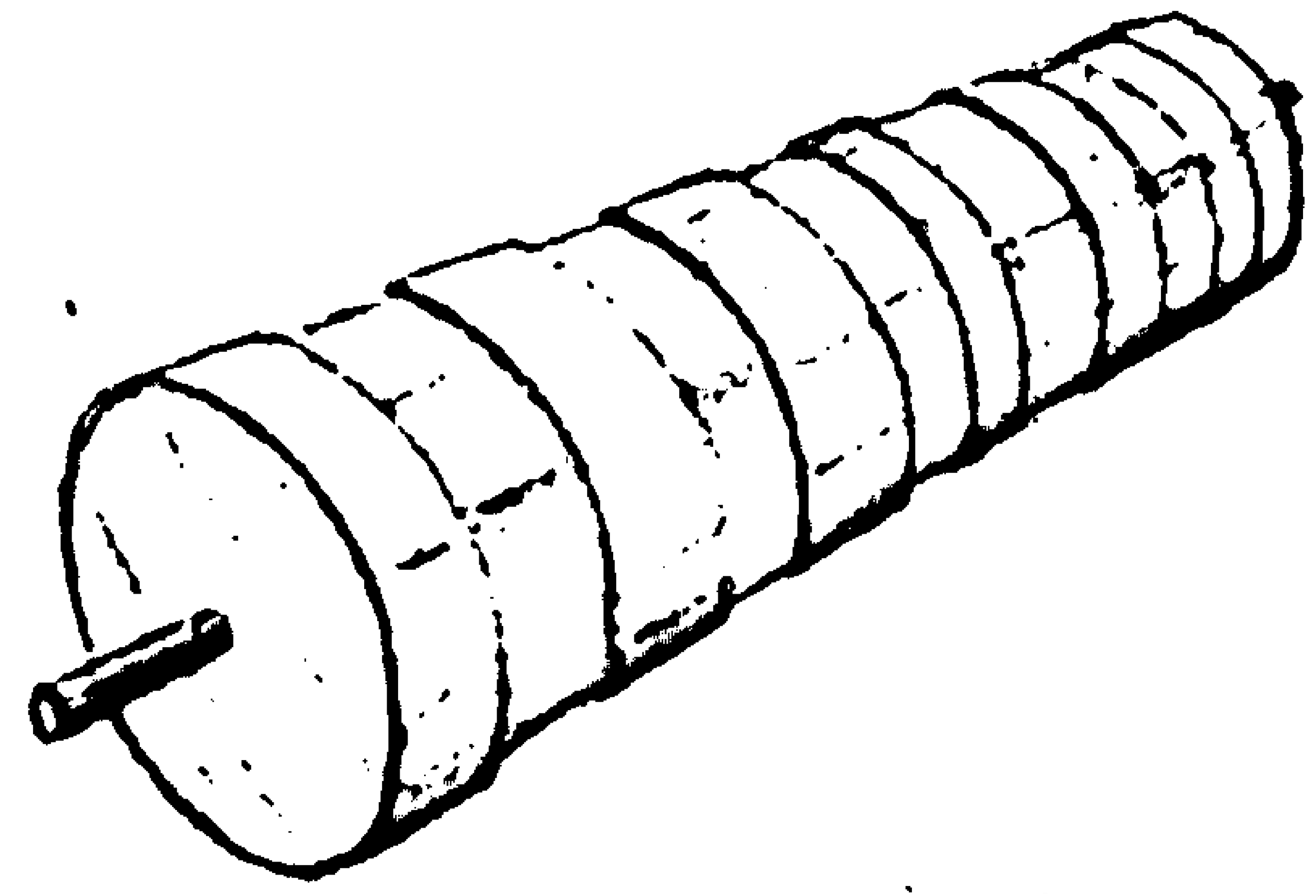


- The Driving-wheel (w1):



The wheel is made of wooden square-bar around which four square-headed wooden-rods are set parallel to each side of the bar. Two vertical and horizontal metal axes that penetrate through the square-bar hold each rod at either end. The wheel is erected at the back of the feeding-tank where the top point on its circumference is in line with the parallel point on the pots-wheel. This wheel rotates smoothly on two bearings. Three ropes (r1, r2, r3) are attached to the wheel on its parallel-rods; the first one equals the length of the pots'-rope plus the distance between the two wheels. This rope is fastened at one end to one of the parallel rods on the driving-wheel and wound around the wheel whilst its other end is attached to the middle groove on the pots-wheel. The second rope has the same length as the pots'-rope is fastened at one end to another parallel rod on the wheel whilst the other end is fastened at the top of the lever. The third rope, which also has the same length as the pots' rope is fastened at one end to a free parallel rod on the wheel and wound around the wheel in the opposite direction of the first one. A falling-weight (f) is attached to the other end of this rope.

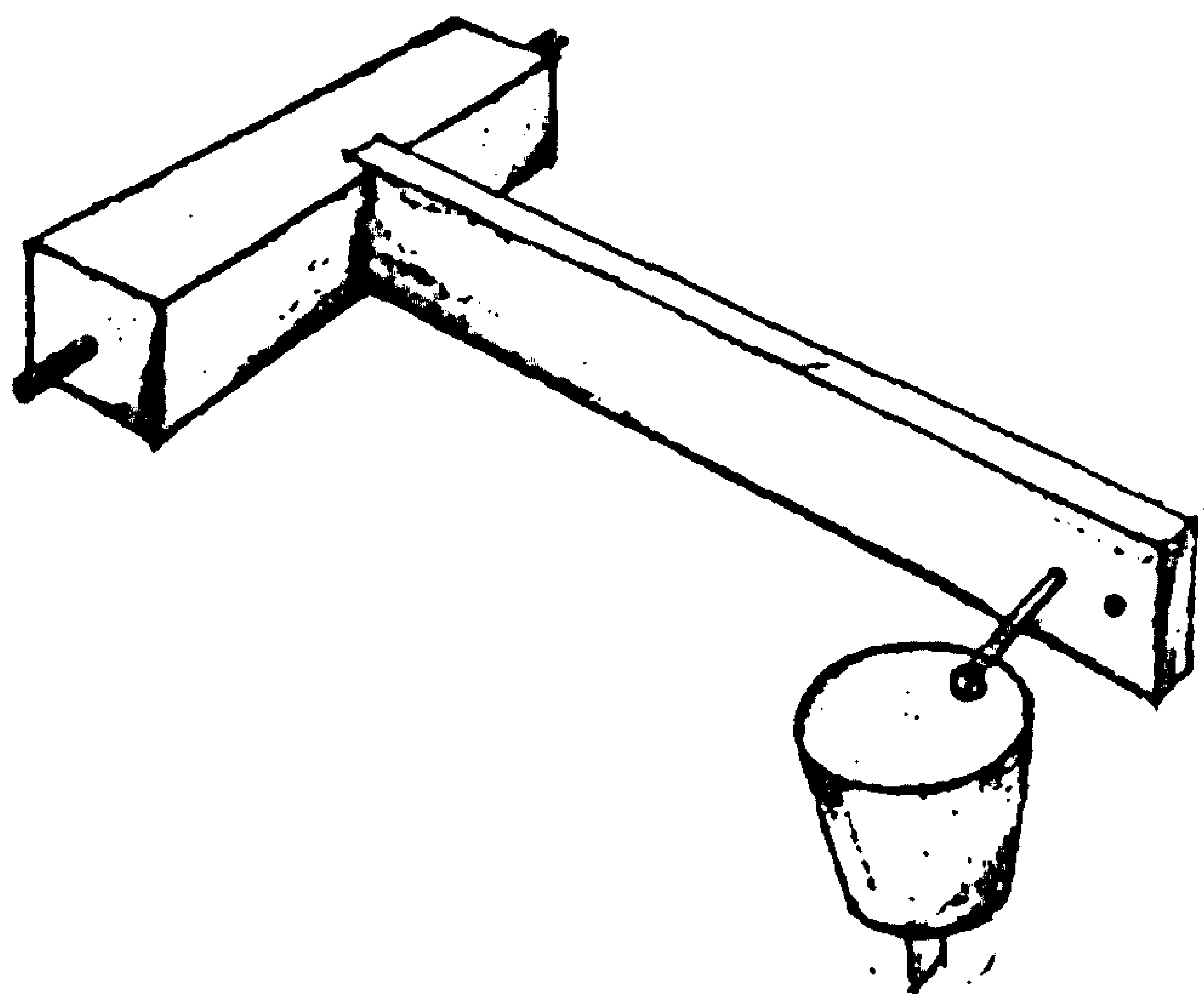
- The Pots-wheel (w2):



This wheel is made of a wooden cylinder that rotates on two bearing. Two parallels grooves at either end are made to which the ropes of the two pots are attached. A middle groove is made as well, to which the first rope of the driving-wheel is attached.

- The Lever (l):

The shape of this lever forms the letter 'T' as shown in the drawing; and its axle rotates on two bearings. It is positioned beneath the driving-wheel where its centre is perpendicular with the axes of the driving-wheel. On its far end, two holes are made; on the first of which the second rope of the driving-wheel is fastened, and on the second hole an axle is attached on which a small vessel rotates very smoothly. This vessel has a metal projection on its bottom, which is designed to strike the sub-tank causing the vessel to empty out its contents.

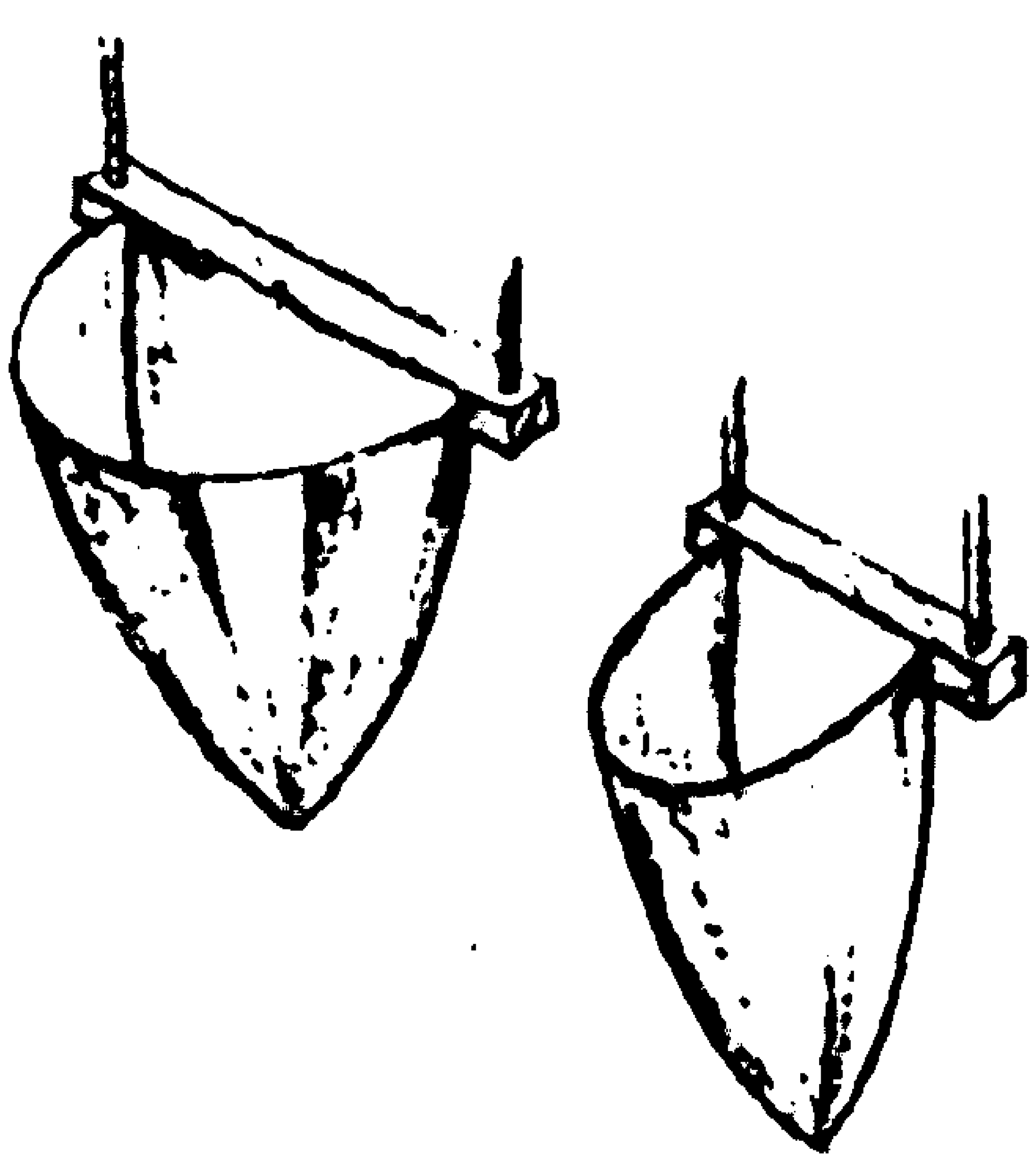


- The falling-weight (f):

This weight is attached to the third rope (r3) of the driving-wheel and has the role of lifting up the full delivery-pots and the lever with its empty vessel at the same time.

- The Delivery-pots (b1, b2)

There are two pots; one is twice as big as the other. Close to the bottom of each one, a horizontal projection is attached which causes the pot to tilt on its side and submerge into the supply-tank. Each pot is attached to the pots-wheel by two ropes.



- **How the perpetual fountain works**

In this description of the operation of the fountain I will concentrate on the main mechanism of the machine. Therefore I will avoid the elaborated description introduced by the engineer concerning the automated figures and the setting of the cascade, as far the mechanism concept of the fountain and its machinery are concerned. For a clear understanding of the fountain, this description is to be read in conjunction with my reconstruction drawing, figure (1).

Initially the fountain basin (g) and the two tanks (t1, t2) are filled with water, so the water must be at the same level in all of them, as they are connected to each other. To set the machine in motion the falling-weight (f) is brought up by rotating the driving-wheel (w1) to wind up its rope around it. The ropes (r1, r2) of both the pots-wheel (w2) and the lever (L) are consequently released from the driving-wheel (w1). So the two pots (b1, b2) are fully submerged into the supply-tank (t1) and ready to be launched. By releasing the falling weight (f) a rotation of the driving-wheel is caused, winding up the ropes of the pots-wheel and the lever. This will result in a rotation of the pots-wheel, lifting up the two pots where they empty out their contents into the feeding-tank (t2), as they hit the receiver of the tank. Thus the water in the small pot (b2) goes into the small section of the tank while the big pot (b1) pours out into the big section. Through pipe (m) the water passes from the small section of the tank into the vessel (v) that is already brought up right beneath the pipe as its rope is being wound up around the driving-wheel. The water that has been poured out into the big section of the feeding-tank (t2) descends through the pipe (n) that terminates at the fountain-head to produce a vertical jet. Meanwhile the water that has been poured out into the vessel exerts a force on the lever making it tilt down quickly where the projection of the vessel hits the edge of the sub-tank (t3) to pour out its contents into the tank. By this movement the machine returns to its initial position, so the falling-weight is uplifted again and the delivery-pots are sunk back into the supply-tank, where the operation is repeated. The water that is emitted from the fountain-head falls back into the basin (g), which is connected to the two tanks (t1, t3), and this means that the water stays at the same level in the supply-tank, and can be delivered to the feeding-tank again and again.

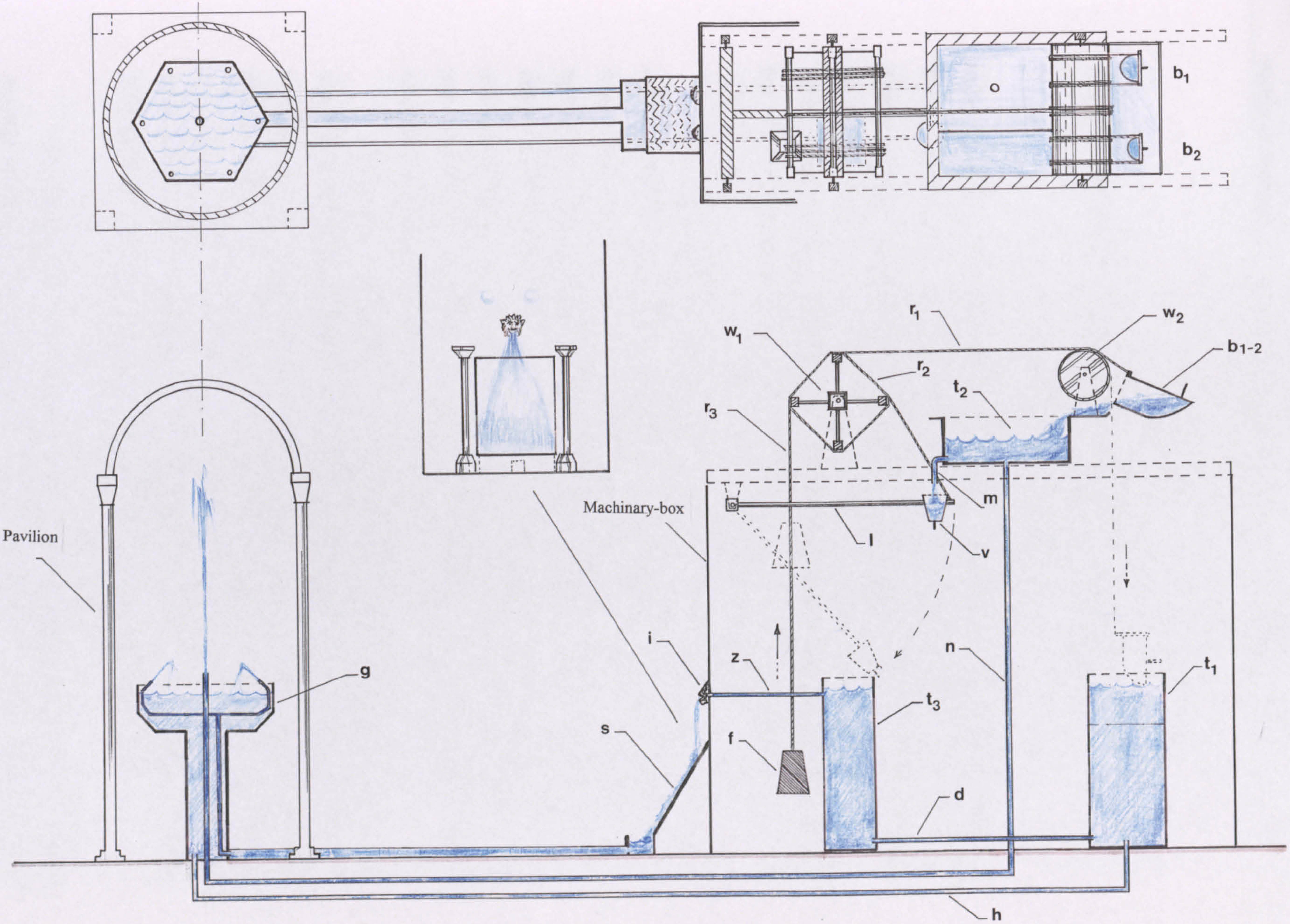


Figure 1: Reconstruction of the fountain and the cascade and their Machinery. The whole structure represents the most distinctive water-feature in Islamic architecture, The *Salsabil.*

The Experimental work on the fountain's mechanism

From the previous description of the perpetual fountain that its mechanism may, in theory, appear to us, as it did to the engineer, rather convincing, whereas it is by all means impractical. The engineer inclined to base his mechanical ideas on mere theoretical concepts, in which he found a logical sense of its practicality. Nevertheless the most crucial factor, friction, seems to have escaped his notice, which has always been the case in all attempts to solve the mystery of perpetual motion till modern times.

Even though if we, for the sake of argument, neglect this crucial factor, and suppose that the machine satisfactorily works, at least the inevitable loss of water would seize its movement after a number of rotations. In my experimental work, I have tried to examine and provide a clear understanding of main engineering ideas the design of this machine was based on. The first intelligent design idea is the levering mechanism that is operated by use of water to exert a force on the free-end of the lever, which is interestingly connected to the second engineering idea that is based on the falling-weight mechanism.

Although the design looks at first glance quite simple, the complication of the connection ropes, the setting of the wheels, and the arrangement of the lever reveal to us a genuine idea of design, which requires a great deal of engineering knowledge. In the full-scale model I have reconstructed I inclined to follow the instruction given by the engineer and tried at every convenient point to stick to the materials prescribed, even where modern versions that are clearly superior exist i.e. Bearings. Figures 2,3,4,5,6 and 7 show the reconstruction of the machine's component parts.

My experiments have mainly focused on the examination of the two operating mechanism, the levering and falling-weight mechanisms. I have tried to reach the best possible result of each component by conducting a series of adjustment of the relative horizontal and vertical distance between each component part of the machine. This, in fact, may tell us more about the actual principles involved as this machine will be horizontal and vertical distance between each component part of the machine. This, in fact, may tell us more about the actual principles involved as this machine will be cross-examined with a number of perpetual-motion machine designed by other Muslim engineers. Also this experiments may inform us to what extend this machine would operate before ending in complete halt, so we may determine how far or close the engineer was from achieving what he supposed to be an absolute perpetual-motion machine. Tables 1 to 5 show the data of the experiment I have carried out, which in fact do not present any significance. But at least it inform us that despite the fact that the engineering ideas incorporated in this machine may be regard as innovative, in terms of its design, the operation of which is no more than an ambitious imagination. The definite result of these experiments I have been able to conclude is that since the margin between the amount of water lifted up from the supply-tank and the water needed to exert force on the lever causing it to tilt rapidly is almost immeasurable, the machine seemed to cease completely after the first motion. Therefore I will confine the results of the experiments to the data tables without any further explanation.

Having subjected the claims within this manuscript to a practical interrogation through experiment, my conclusion must be that the claims are false, and the mechanisms described are unworkable. Research into the concept of perpetual motion in relation to Islamic engineering in general and the fountain in particular could not progress beyond this isolated document. The alternative has been the study of the fountain as the investigated manuscript describes one of the most exquisite fountains in Islam. This consequently has led to the study of the fountain design and engineering tracing its history from the ninth to the sixteenth centuries, which represents the climax of scientific and artistic achievements in the history of civilisations. The following chapters investigate the fountain in the work of Muslim engineers and also introduce the philosophy of the fountain in the culture of Islam.

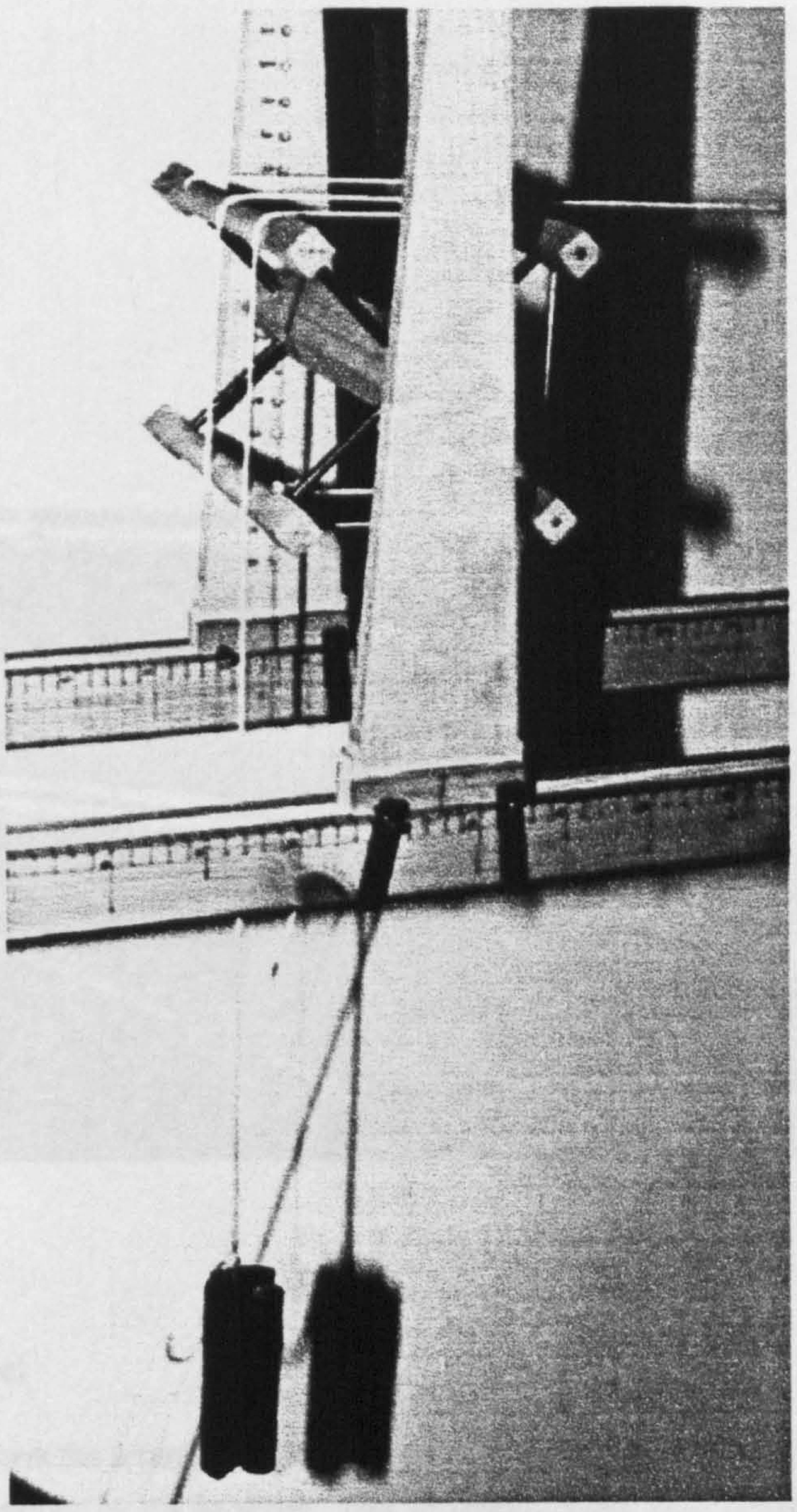


Figure (2) The driving-wheel and the falling-weight

This picture shows the examination of the driving-wheel. The two square-bars that make the base of this wheel are divided in centimetre to allow horizontal adjustment by sliding the holding-arms of the wheel into the groves. These two arms are divided as well to allow vertical adjustment of wheel's bearings.

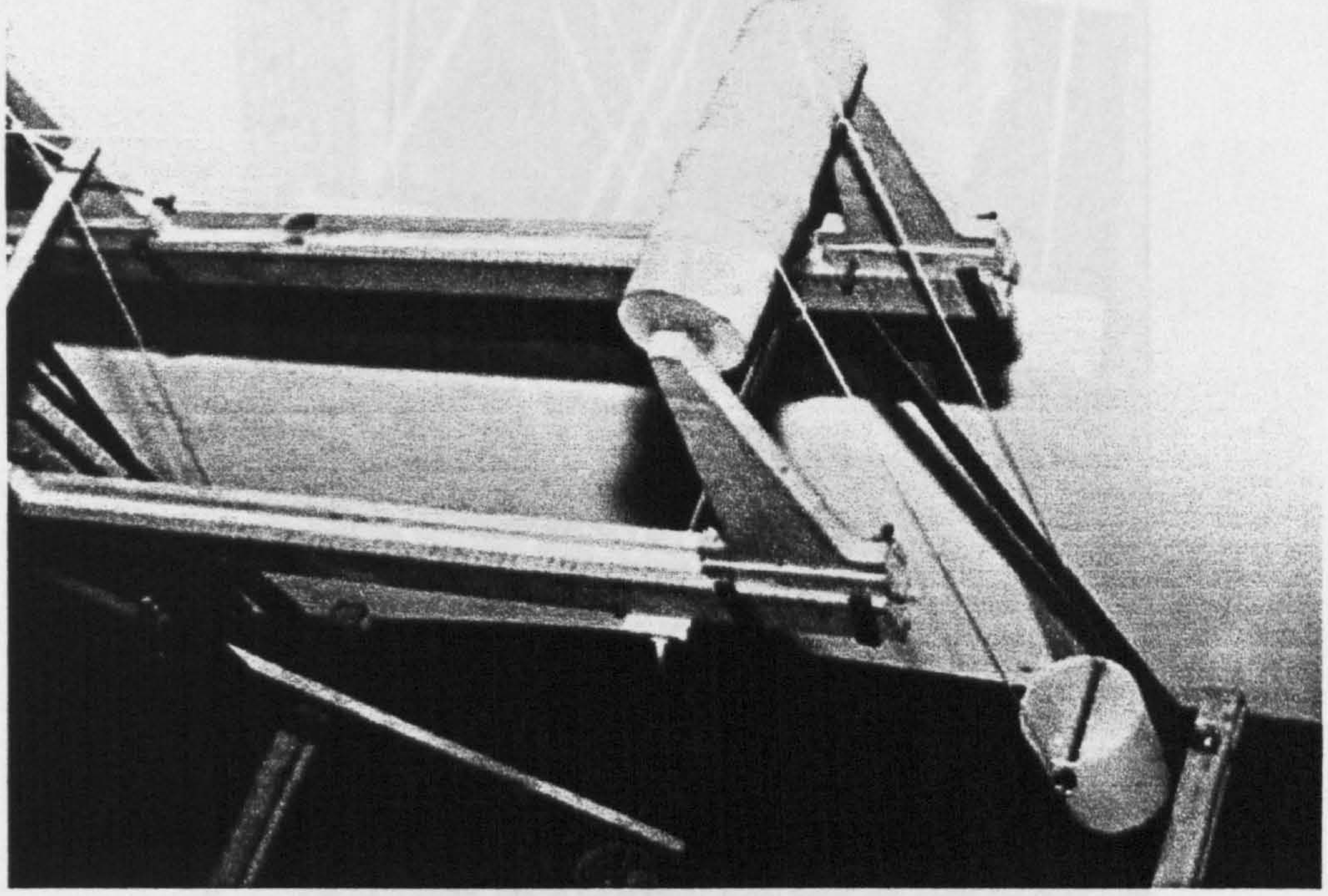


Figure (3) Pots-wheel

This picture shows the arrangement of the wheel in which I have used one pot instead of two as originally designed by the engineer. This alteration, in fact, dose not affect the structure of machine.

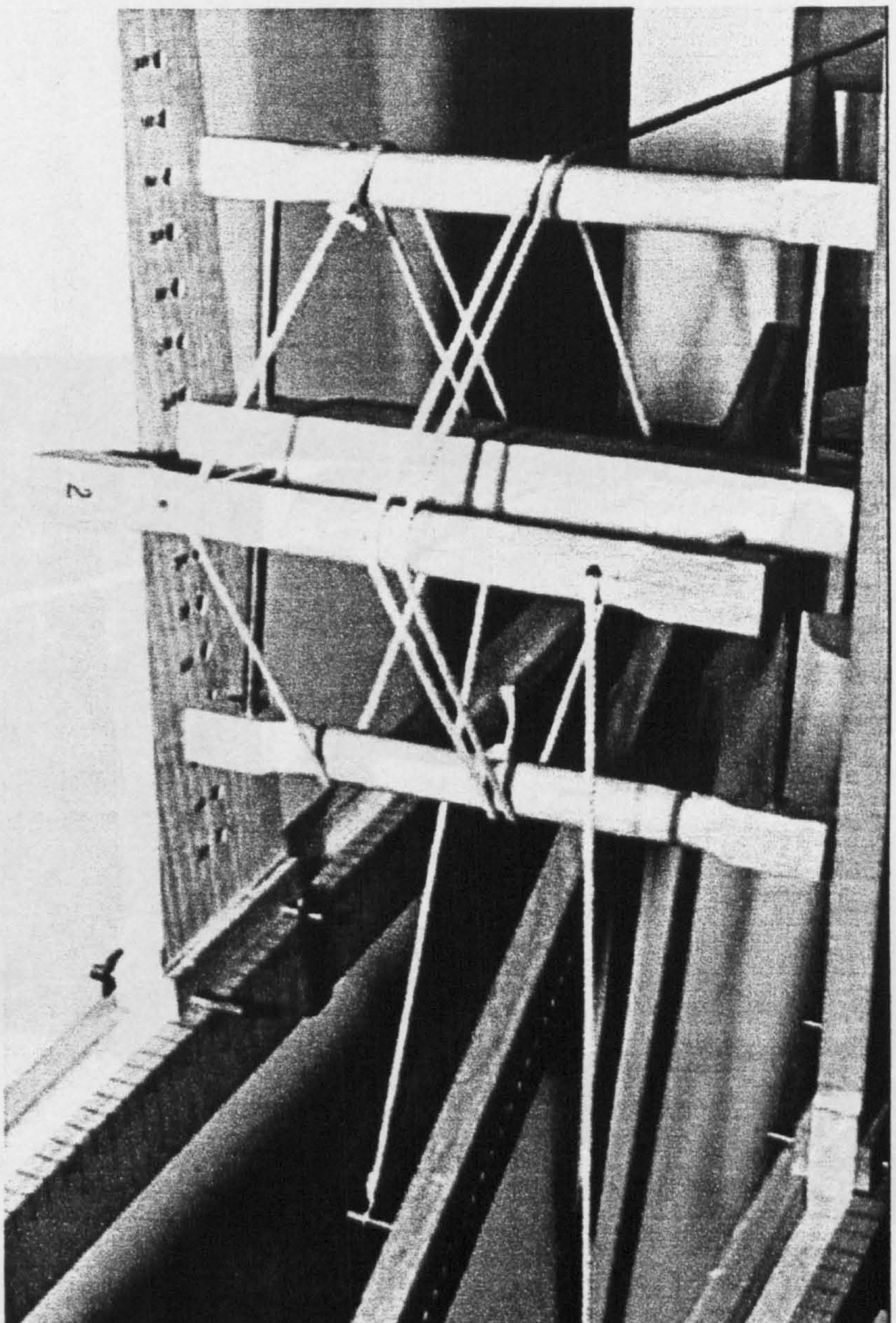


Figure (4) Driving-wheel

This picture shows the construction of the driving-wheel. It also shows the complicated arrangement of the ropes that connect the three components of the machine: the driving-wheel, pots-wheel and the lever.

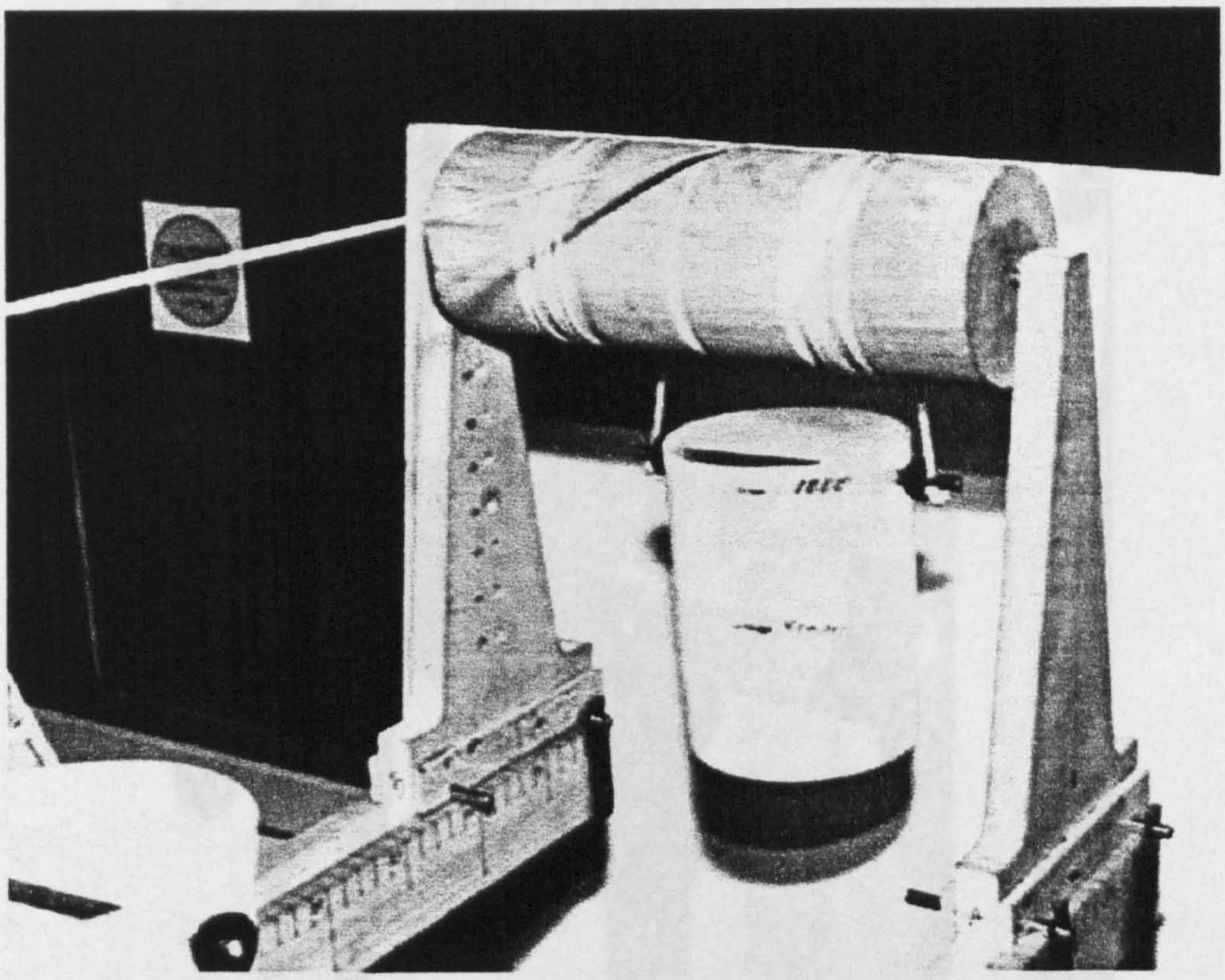


Figure (5) Delivery-pot and Pots-wheel.

This picture shows the arrangement of the wheel and the setting of its bearings adjustment. The wheel is also repositioned horizontally by sliding it into its base.

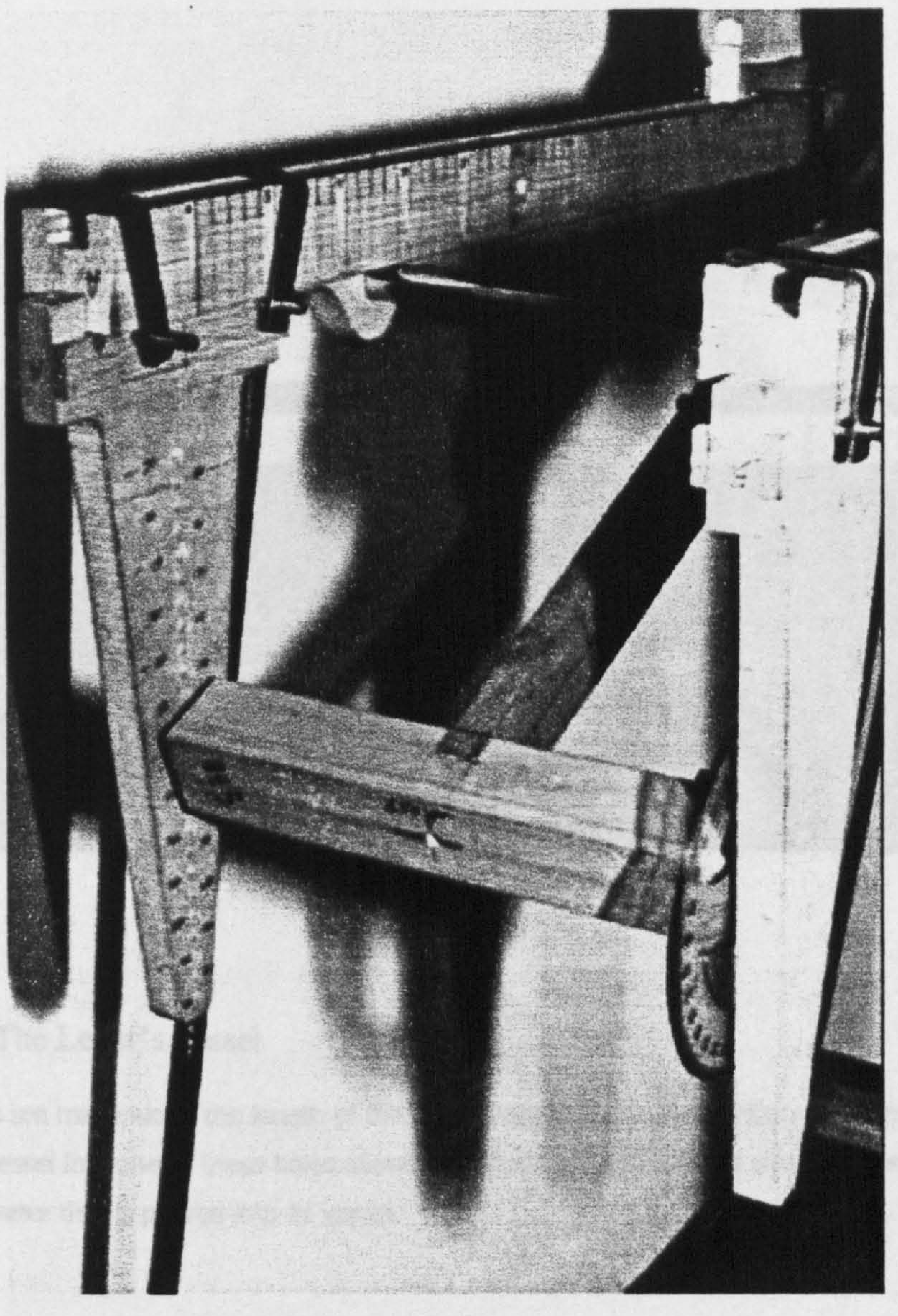


Figure (6) The lever

This shows the adjustment setting of the lever's bearings. The lever is adjusted by repositioning its bearings into the holes made on the two holding-arms. The angle of the lever is also determined to allow better calculation of its performance.

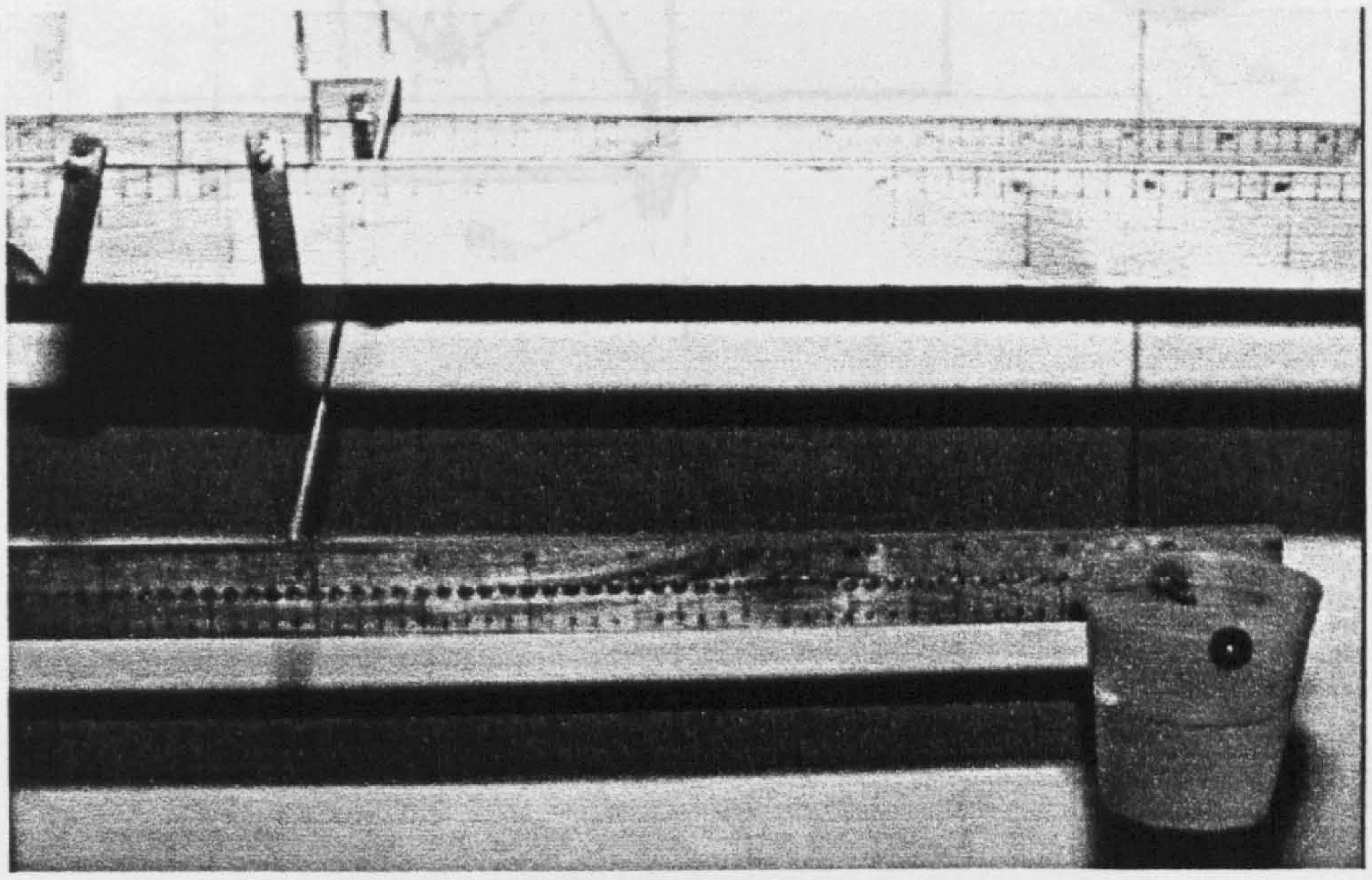
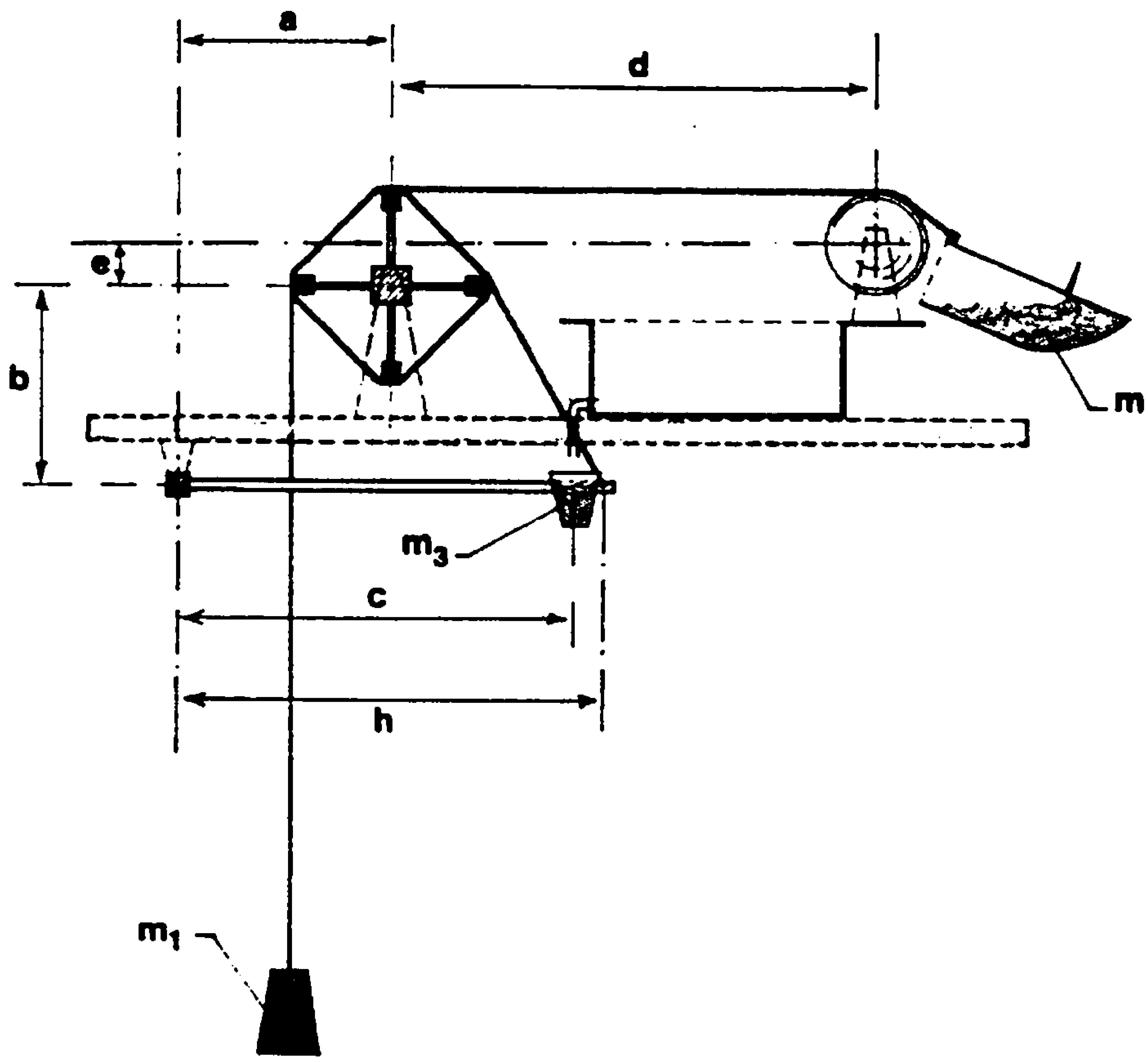


Figure (7) The Lever's vessel

Holes are made along the length of the lever dividing it into centimetres. The positioning of the vessel into one of these holes allows an adjustment of the force exerted upon the lever by the water that is poured into its vessel.



a : Horizontal span between the lever's axle and the axle of the main-wheel.

b : Vertical span between the lever's axle and the axle of the main-wheel.

c : Distance between the centre of the lever's vessel (dragging vessel) and its axle.

d : Horizontal span between the main-wheel's axle and the axle of the pots- wheel.

e : Vertical span between the main-wheel's axle and the axle of the pots- wheel.

g : Length of the lever.

h : Distance between suspension point (rope tighten point) of the lever and its axle.

m1 : Weight of the Falling-weight.

m2 : Amount of the water lifted.

m3 : Amount of the water needed for the (lever's vessel).

(All measurements are in millimetre and gram)

Table one.

The best result obtained from these experiments is 450 ml. of water that is lifted from the supply tank by the force of 1000 gr. of the falling-weight. However 400 ml. of that water is needed to lift up the falling-weight to its normal position. So the 50 ml. of water left is so little even to operate a very tiny fountain.

Exper.	Lever			Main-wheel		Falling-weight	Pots-wheel		
	H	C	M3	A	B	M1	D	E	M3
1	690	1000	450	690	500	1000	650	40	450
2	680	~	450	680	~	~	660	~	450
3	670	~	400	670	~	~	670	~	450
4	660	~	400	660	~	~	680	~	450
5	650	~	400	650	~	~	690	~	400
6	640	~	350	640	~	~	700	~	380
7	630	~	400	630	~	~	710	~	400
8	620	~	400	620	~	~	720	~	400
9	610	~	350	610	~	~	730	~	400
10	600	~	350	600	~	~	740	~	350
Best result No. 3			**400**			**1000**			**450**

Table two.

The best result obtained from these experiments is 350 ml. of water that is lifted from the supply tank by the force of 1000 gr. of the falling-weight. However 300 ml. of that water is needed to lift up the falling-weight to its normal position. Also the motion is very slow and the 50 ml. of water left is so little to operate any sort of fountain.

Exper.	Lever			Main-wheel		Falling-weight	Pots-wheel		
	H	C	M_3	A	B	M_1	D	E	M_3
1	590	1000	325	590	500	1000	750	40	330
2	580	~	300	580	~	~	760	~	350
3	570	~	300	570	~	~	770	~	340
4	560	~	300	560	~	~	780	~	320
5	550	~	280	550	~	~	790	~	300
6	540	~	280	540	~	~	800	~	300
7	530	~	280	530	~	~	810	~	300
8	520	~	300	520	~	~	820	~	300
9	510	~	300	510	~	~	830	~	290
10	500	~	280	500	~	~	840	~	290
Best result No. 3			**300**			**1000**			**350**

Table three.

The data of the ten experiments shown in this table and also in the next two table show the amount of water lifted by the pots from the supply-tank is equal or lesser than the amount is needed to exert a force on the lever to pull up the falling-weight to its normal position and at the same time to bring down the delivery-pots.

Exper.	Lever			Main-wheel		Falling-weight	Pots-wheel		
	H	C	M_3	A	B	M_1	D	E	M_3
1	490	1000	260	490	500	1000	850	40	260
2	480	~	250	480	~	~	860	~	240
3	470	~	250	470	~	~	870	~	240
4	460	~	250	460	~	~	880	~	210
5	450	~	220	450	~	~	890	~	200
6	440	~	200	440	~	~	900	~	190
7	430	~	190	430	~	~	910	~	170
8	420	~	160	420	~	~	920	~	150
9	410	~	150	410	~	~	930	~	125
10	400	~	140	400	~	~	940	~	120
Best result No. 0			x			x			x

Table four.

Exper.	Lever			Main-wheel		Falling-weight	Pots-wheel		
	H	C	M_3	A	B	M_1	D	E	M_3
1	710	1000	480	710	500	1000	650	40	450
2	720	~	490	720	~	~	660	~	420
3	730	~	490	730	~	~	670	~	450
4	740	~	490	740	~	~	680	~	440
5	750	~	500	750	~	~	690	~	420
6	760	~	500	760	~	~	700	~	410
7	770	~	500	770	~	~	710	~	410
8	780	~	500	780	~	~	720	~	410
9	790	~	510	790	~	~	730	~	420
10	800	~	525	800	~	~	740	~	450
Best result No. 0			x			x			x

Table five.

Exper.	Lever			Main-wheel		Falling-weight	Pots-wheel		
	H	**C**	**M3**	**A**	**B**	**M1**	**D**	**E**	**M3**
1	700	1000	440	700	500	1000	640	40	440
2	690	~	450	~	~	~	~	~	450
3	680	~	430	~	~	~	~	~	450
4	670	~	440	~	~	~	~	~	440
5	660	~	440	~	~	~	~	~	440
6	650	~	440	~	~	~	~	~	440
7	640	~	440	~	~	~	~	~	400
8	630	~	440	~	~	~	~	~	440
9	620	~	430	~	~	~	~	~	340
10	610	~	380	~	~	~	~	~	330
Best result No. 2			**450**			**1000**			**450**

Perpetual Motion in the Work of Muslim Engineers

1. Hans Schmeller's Study

Hans' study of the history of perpetual motion in the engineering of Islam is regarded as the most serious and the only one of its kind since its publication in 1922. He devoted a chapter in his article to studying number of machines of the perpetual motion type known to him, which are scattered in several manuscripts kept in Western libraries. Hans' study, however, was not privileged with a wide publication, which mainly contributed to its limited circulation to the people with knowledge of German and the to the difficult accessibility of the journal in which the article had been published. As far as my study is concerned, I could not have been able to study Hans' work without the Arabic translation manuscript of Hans' work with which Prof. Ahmad al-Hassan kindly has provided me. Although this manuscript has no diagrams, it has been of great help to me. So I requested the original German journal in which Schmeller had published his article through a foreign inter-library-loan application, which took several months to arrive.

In the second chapter of his article, Schmeller investigated a number of water-lifting machines, one of which is a perpetual motion type, and seven perpetual motion machines, which were set to generate energy, are investigated in the following chapter.

We gather that Schmeller referred to the mechanical concepts which were described in the work of Banu Musa and al-Jazari in order to make a clear understanding of the machines he investigated. This was a demanding task especially in the process of matching up the rather ambiguous description and contradictory drawing of a single machine in different manuscripts as well as the materials and techniques used. On this, Schmeller informs us that:

" The descriptions in many paragraphs of Leiden manuscript are in most cases not presentable. Therefore the impression that might be imposed is that the copyists could not understand the models and most probably the authors themselves had intentionally dropped-out some components of the machines in order to make them look rather peculiar. We find such example, even in a minute percentage, in Banu Musa and al-Jazari works"[1].

Although we may agree with Schmeller on the assumption that there were a number of misunderstandings by the copyists, which made the machines appear rather ambiguous, and the tendency among the authors to keep some of the machines secrets to themselves, but the later assumption could not be pertinent to the case of Banu Musa and al-Jazari. The fact that has been introduced by the studies of Hill and al-Hassan confirms that Banu Musa and al-Jazari did not pay attention to the physics and mechanical principles on which their machines were based. They, Banu Musa and al-Jazari, however, had the tendency to concentrate upon a simple presentation of the machines' constructions and techniques, avoiding the complication of their physics and mechanics. On the other hand Banu Musa and al-Jazari, I believe, were well aware of the people to whom their books were orientated. Engineers and craftsmen were the professionals who would significantly benefit from such plain presentation of the machines described. This is why their books enjoyed a wider range of circulation, which may not have been the case if they were scientifically orientated. The fact is that to engineers such scientific explanations of the concepts involved may have seemed not fundamentally necessary. Giving an example, we find that al-Jazari some three hundred years later studied the Book *al-Hiyal* of Banu Musa, which offered no comments on the scientific aspect, however al-Jazari was critical of the efficiency of some concepts, like the interval time of the fifth fountain.

[1] Schmeller, Hans (1920) Beitrage zur Geschicchte der Technik in der Antike und bei den Arabern. *in* Prof. Oskar Schulz, Erlangen (ed) *Abhandlungen zur Geschichte der Naturwissenschaften und der Medizin*. Heft VI. Erlangen: Kommissionsverlag von Max Mencke. p. 3.

This familiarity with scientific concepts among the engineers is found also in the *Al-Risalaa al-Qudsiya* and Taqi al-Din's work some centuries later. Whereas the other stream, the craftsmen, were supposed to have no interest in the scientific concepts of the machines; and it suffices to know that Banu Musa, although they were highly skilled practitioners, had craftsmen who worked for them to execute their machines. Schmeller also comments on the tendency among Muslims to enrich their work with various patterns of embellishment and decoration. He writes, "although the draftsman of the Leiden manuscript was trying to be more closer to the original shape of the machine, the embellishment of its components with decorative straps and patterns manifests that sense of decoration among Muslims"[2].

This tendency towards decorative enrichment is presented in whatever happened to be within the ambience that surrounded man in Islam. It is manifested in the calligraphic inscriptions, architectural elements, and all created objects. Muslims, in fact, perceive everything in the surrounding world, whether it is a product of nature or man made, as a reflection of God's beauty. God, He who prescribed beauty in everything and who glorifies Himself as the best fashioner.

As far as the engineering aspect of the machines is concerned, Schmeller came up with the conclusion that there is a wide contrast in describing a particular machine in different manuscripts; moreover an insufficiency in the complete description of the machine components. This of course posed great difficulty when trying to envisage a convincing image of the machine. With the collaboration of the engineer Eilhard Wiedemann, a fundamental modification of drawings of the machines was rather promising. Although the modified reconstruction of the drawings is substantially significant, Schmeller was handicapped by the illusory text, which he literally translated; giving a justification of the difficulty to match the drawing up with its descriptive text.

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[2] Schmeller, Hans (1920) Beitrage zur Geschicchte der Technik in der Antike und bei den Arabern. *in* Prof. Oskar Schulz, Erlangen (ed) *Abhandlungen zur Geschichte der Naturwissenschaften und der Medizin.* Heft VI. Erlangen: Kommissionsverlag von Max Mencke. p. 3.

Through this discussion I will reintroduce the machines investigated by Schmeller giving my comments when necessary. The main objective, however, is to compare the mechanical concepts, which were introduced by unknown engineers to those used in the machine I have investigated in the *al-Risalaa al-Qudsiyya*. This is the first translation and discussion of Hans' work and it should bring into focus the tradition of perpetual motion in the history of Islamic engineering.

Here I shall not refer to the location of manuscripts and their classification as reported by Hans. For general information, however, the manuscripts in which the machines are described are in Oxford, Leiden and Gotha's library collections.

- **Machine No (1)**

In the second chapter Schmeller investigated a water-lifting machine that operated by a perpetual motion mechanism. This machine was described in three manuscripts according to Hans. Figure (8) shows the modified reconstructed drawing. Hans' notes are confined to the construction description of the machine and explanation on the modification to the drawing which he made.

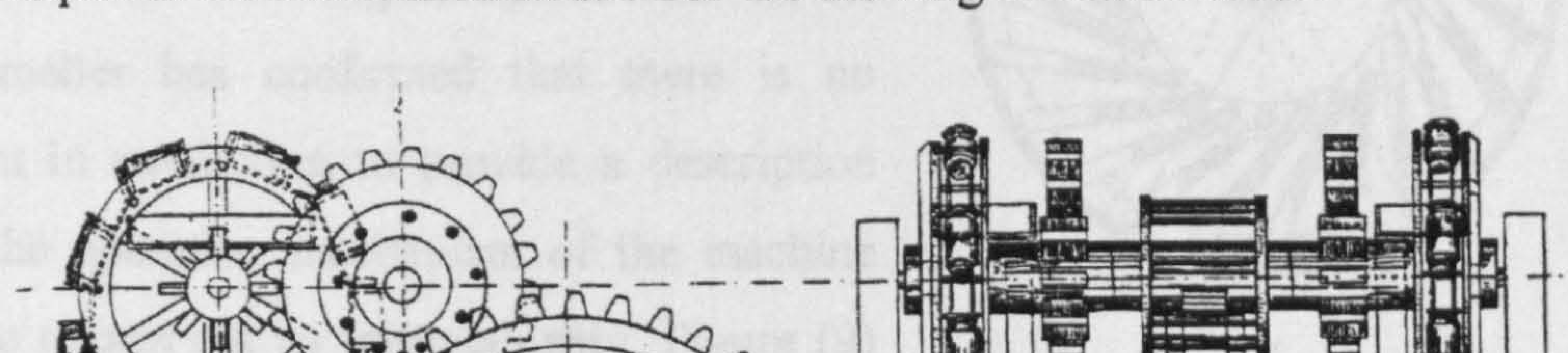

Figure (8)

Although we find no mechanical description on how the machine works and what sort of principles it was based on, we may infer these from the drawing provided.

The operation of this machine seems to be based on the 'falling-weight' mechanism. The lead weights that are attached to two chains are wound, opposite each other, around the either sides of the driving-wheel. The fall of one of these weights is supposed to cause the wheel to rotate and the fall of the other weight is supposed to rotate the wheel back so that the first weight regains its position. This operation is repeated on and on as the machine is set in motion. The delivery of the water is supposed to occur through this dual rotation of the driving-wheel.

It is very obvious that this mechanism is impossible to work even if we agreed for the sake of argument that the two counter-balance weights drive each other. The definite fact then would be that the water, which is carried within the pots, would make the machine completely dead after its first rotation.

- **<u>Machine No. (2)</u>**

Right from the beginning of his notes, Schmeller has confirmed that there is no point in attempting to provide a description of the operation mechanism of the machine or to reason out its impracticality. Figure (9) shows the modified and reconstructed drawing of the machine, which is based on the gravitational force of fluid; which in this case is mercury. Schmeller points out that this machine is quite similar to the water-wheels made of bamboo that were known in the ancient China.

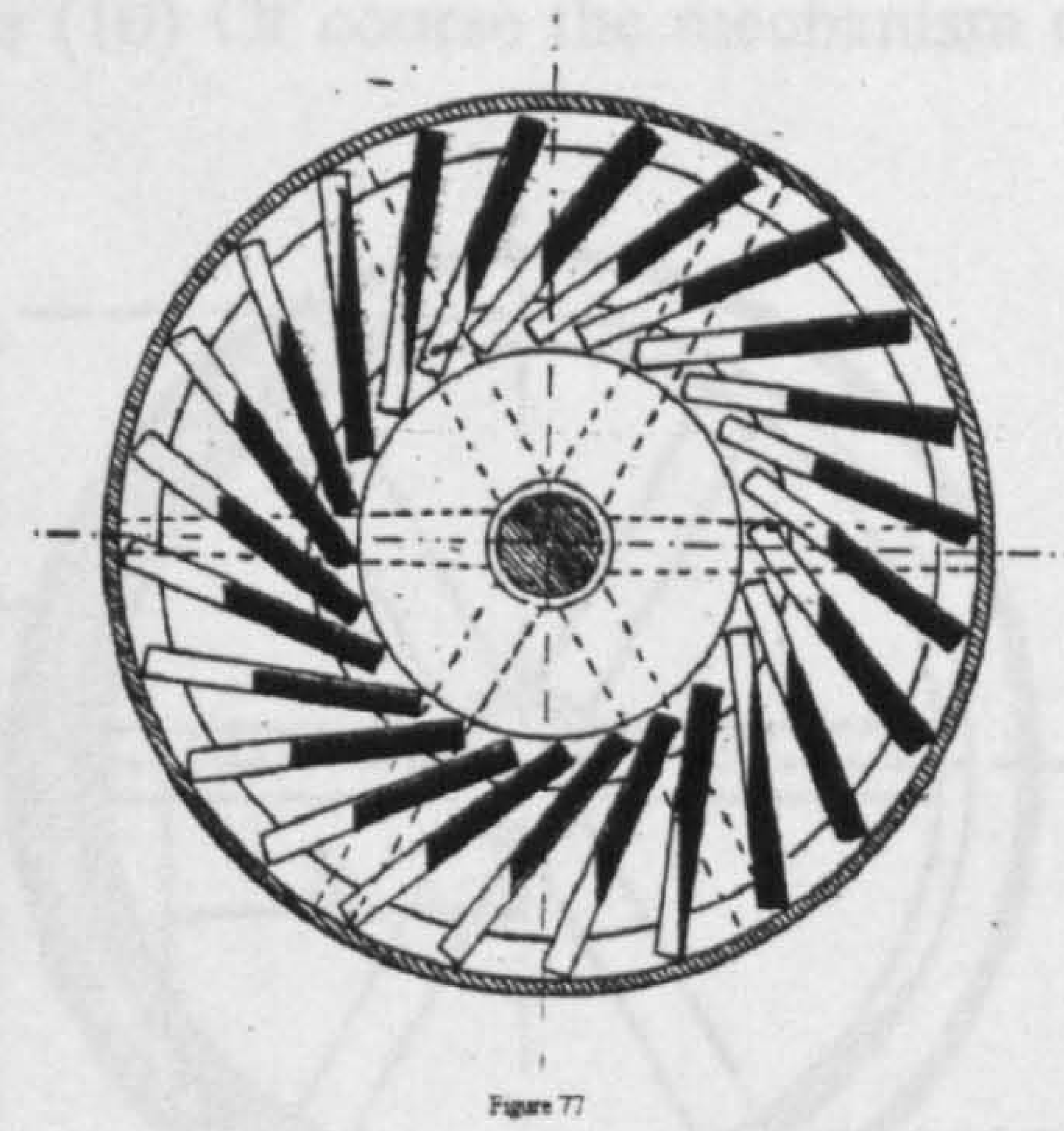

Figure (9)

The machine consists of numerous closed-end tubes partially filled with mercury, arranged at an angle to the radial direction, and fixed around the inner rim of the wheel. So the gravitational force of the mercury in the tubes is being accumulated at one side of the wheel, which lies upon the circumference, while at the opposite side each individual tube lies upon the axis of the wheel and carries its own weight. This mechanical assumption is supposed to drive the wheel as it is set in motion, but in a true mechanical practice this would not work.

- **Machine No. (3)**

This machine is based on the same principle as the previous one, but it is construction is different. Instead of the mercury tubes, there is a cavity around the rim of which is partially filled with mercury and water, See figure (10) Of course the mechanism of this machine, as the previous one, is far from being feasible. Schmeller justifies its impracticability that "as the a distance between of the gravitational centre of the water and the axle is bigger than that of the mercury, the moment of the water then is greater than of the mercury. The author in fact did not think of this implication that the moment of fluid rotation can not be transferred to the wheel".

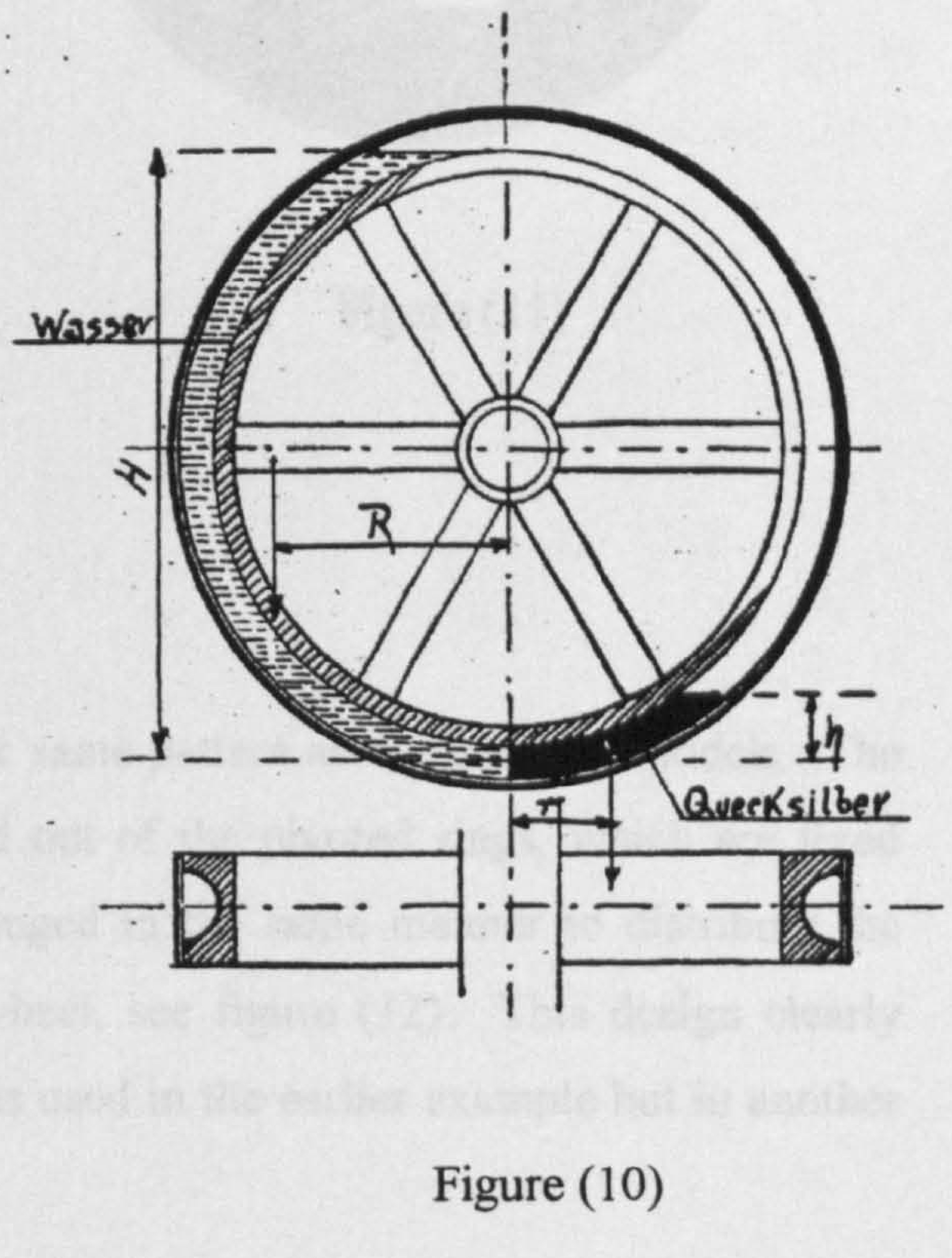

Figure (10)

- **<u>Machine No. (4)</u>**

This machine is based generally on the same principle as the previous models. According to Hans, the text that describes this machine gives no clear explanation of its mechanism. The machine consists of a wheel, which is divided into a number of spiral compartments, which are partially filled with mercury, see figure (11). The gravitational force caused upon the circumference at one side of the wheel is supposed to be much greater than the individual gravitational force of each compartment at the other side on the axis of the wheel. This proposed distribution of force is meant to exert a sufficient movement that would rotate the wheel perpetually once set in motion. Schmeller attributes the failure of this mechanism to the same reasons as the previous model.

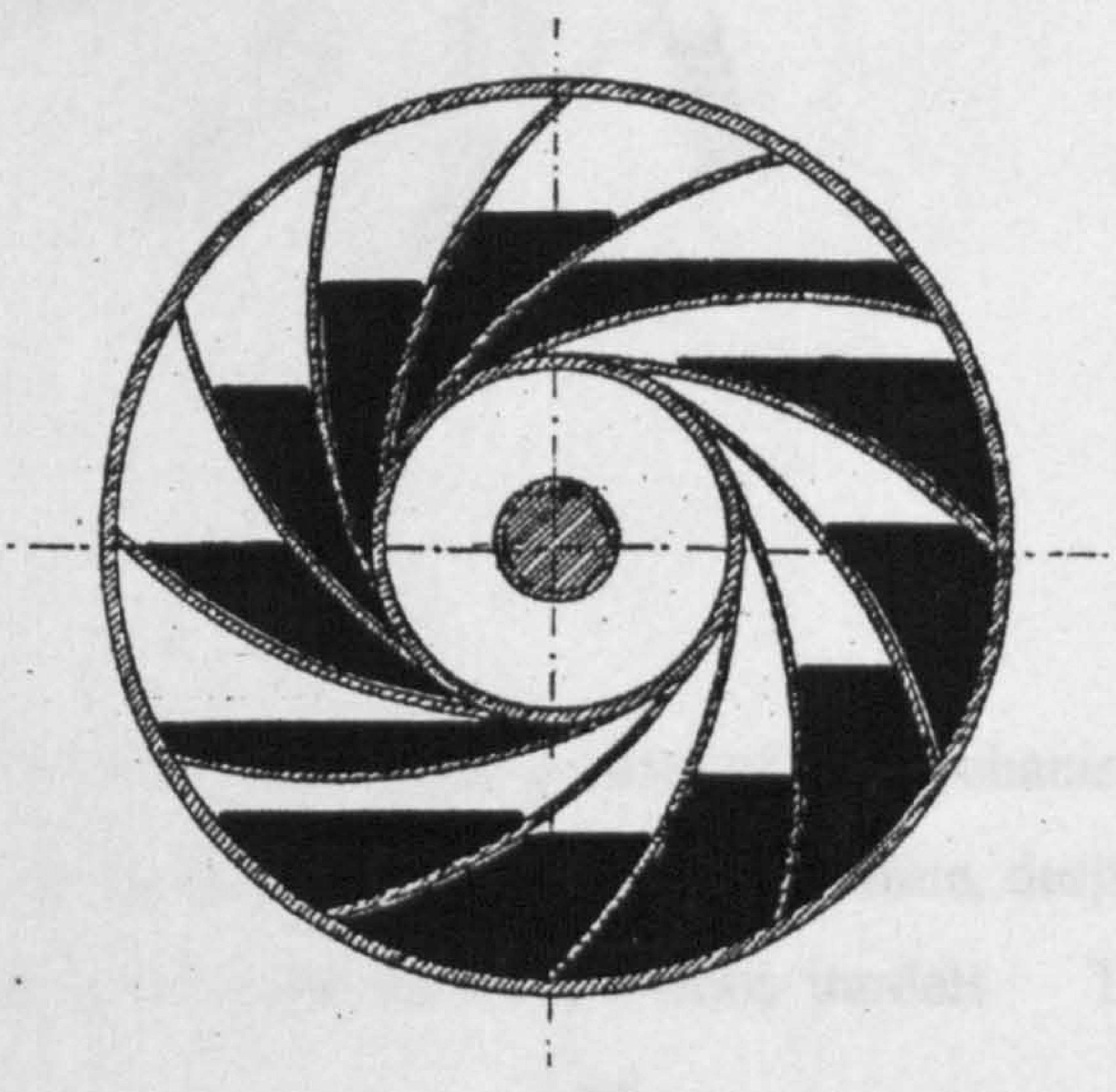

Figure (11)

- **<u>Machine No. (5)</u>**

The design of this machine follows the same pattern as the previous models. The closed-end mercury tubes slide in and out of the pivoted rings, which are fixed around the rim of the wheel and arranged in the same manner to distribute the force between the two sides of the wheel, see figure (12). This design clearly repeats the same wrong principle that is used in the earlier example but in another form of design.

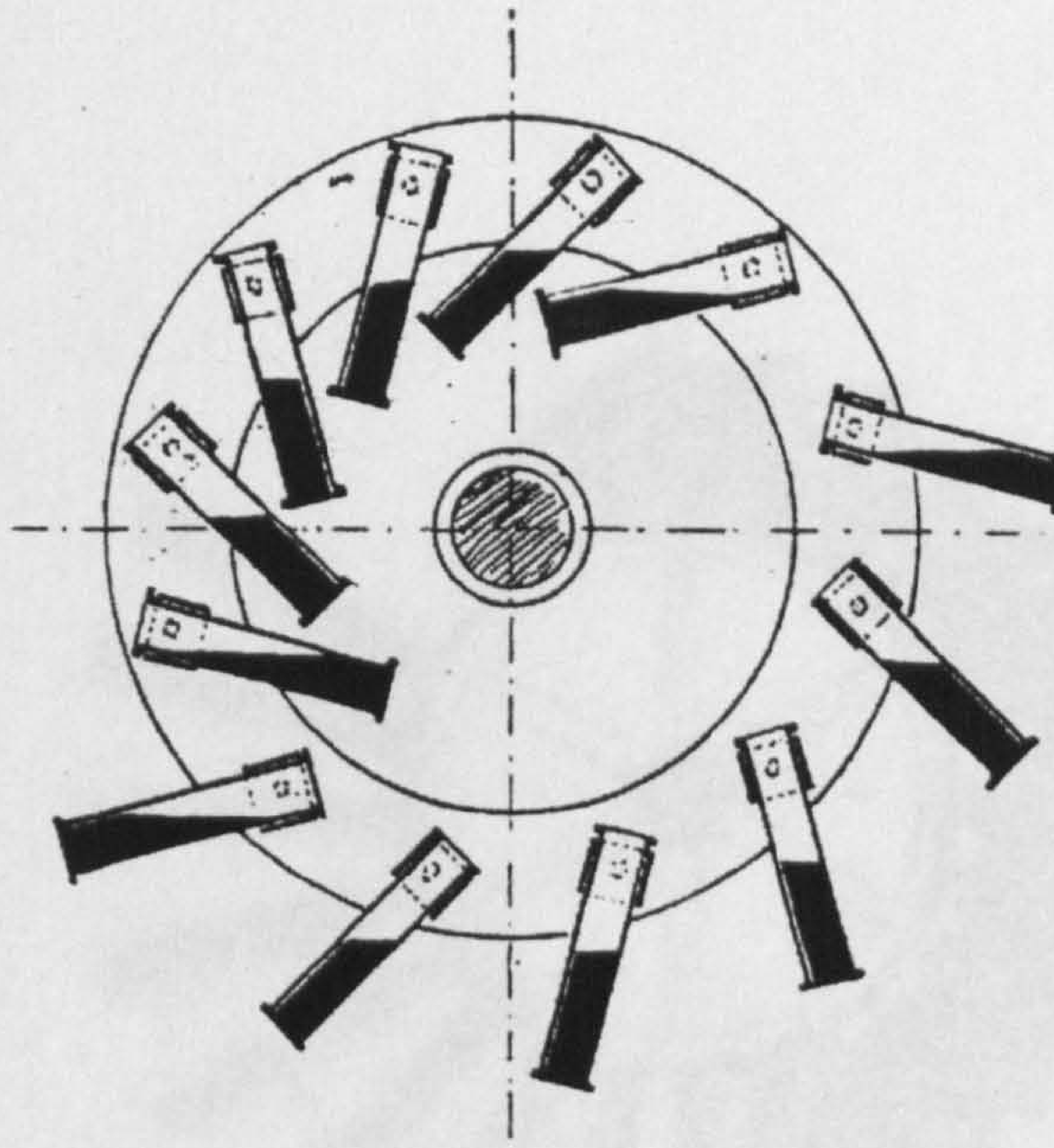

Figure (12)

- **<u>Machine No. (6)</u>**

The modified drawing of this machine provides a clear picture of its mechanism, which Schmeller describes as a new design of a perpetual motion machine, despite the fact that its mechanism is literally the same as the pervious models. The engineer in this design used lead weights instead of mercury. These weights are attached to levers, which are pivoted around the circumference of the wheel. So that in one direction these weights exert force upon the circumference, while at the opposite side being carried along by its weights. (see figure 13) Of course the impracticability of this model is rather clear.

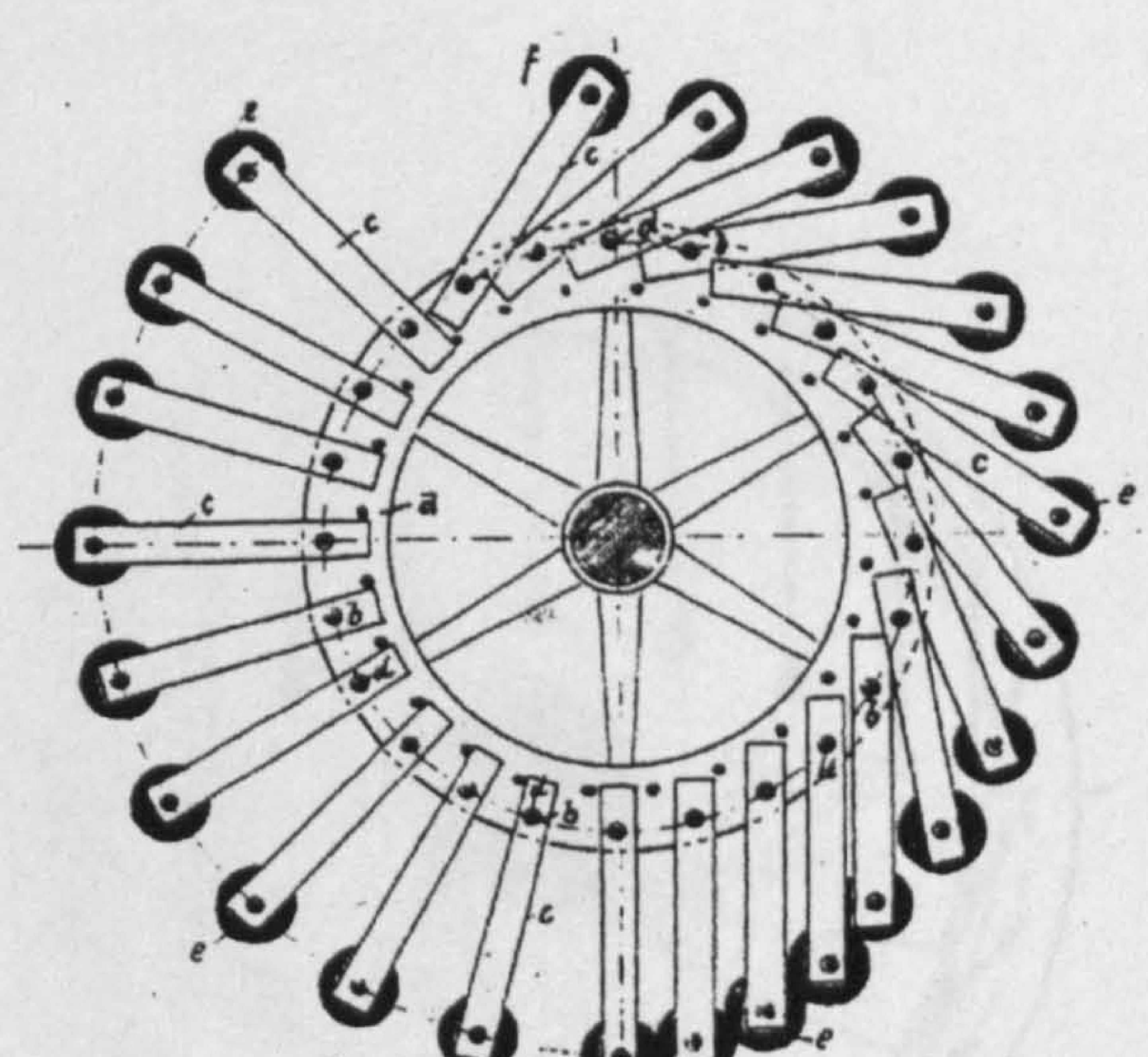

Figure (13)

- **Machine No. (7)**

Although this machine appears in a different design, it again bears the same false mechanical assumptions as the earlier models. Figure (14) shows a wheel with multi-jointed arms hinged to the rim of the wheel, which at one side fold upon each other, while at the opposite side they straighten up to form an individual force that lies upon the axes of the wheel.

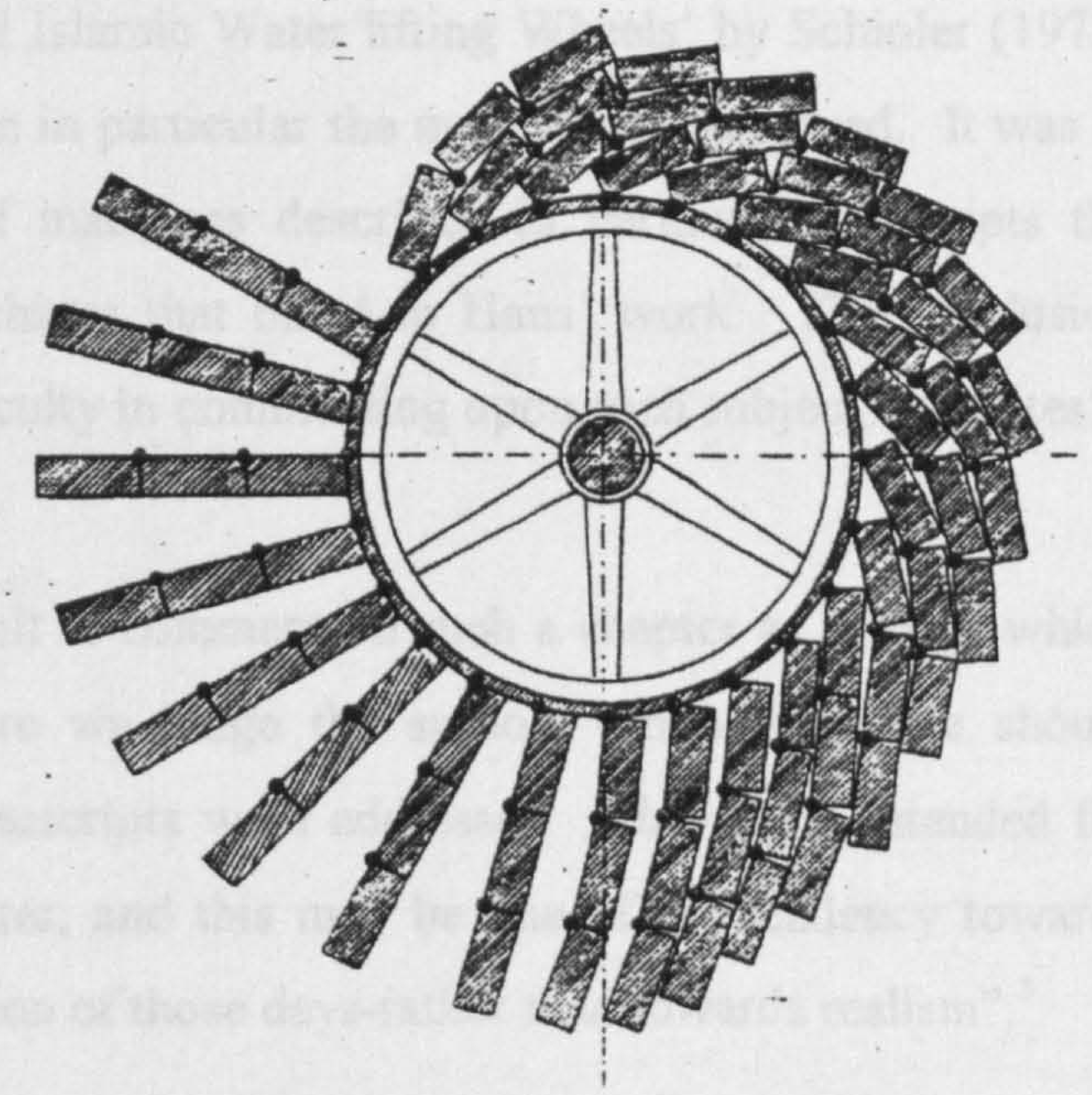

Figure (14)

- **Machine No. (8)**

Schmellercomments about this machine that there is an ambiguous description of the construction of the machine. The most obscured part of its construction is the setting and the arrangement of the chained-weights, figure (15). However, this machine is exactly another copy of the same principle used in the other examples, and is utterly impractical.

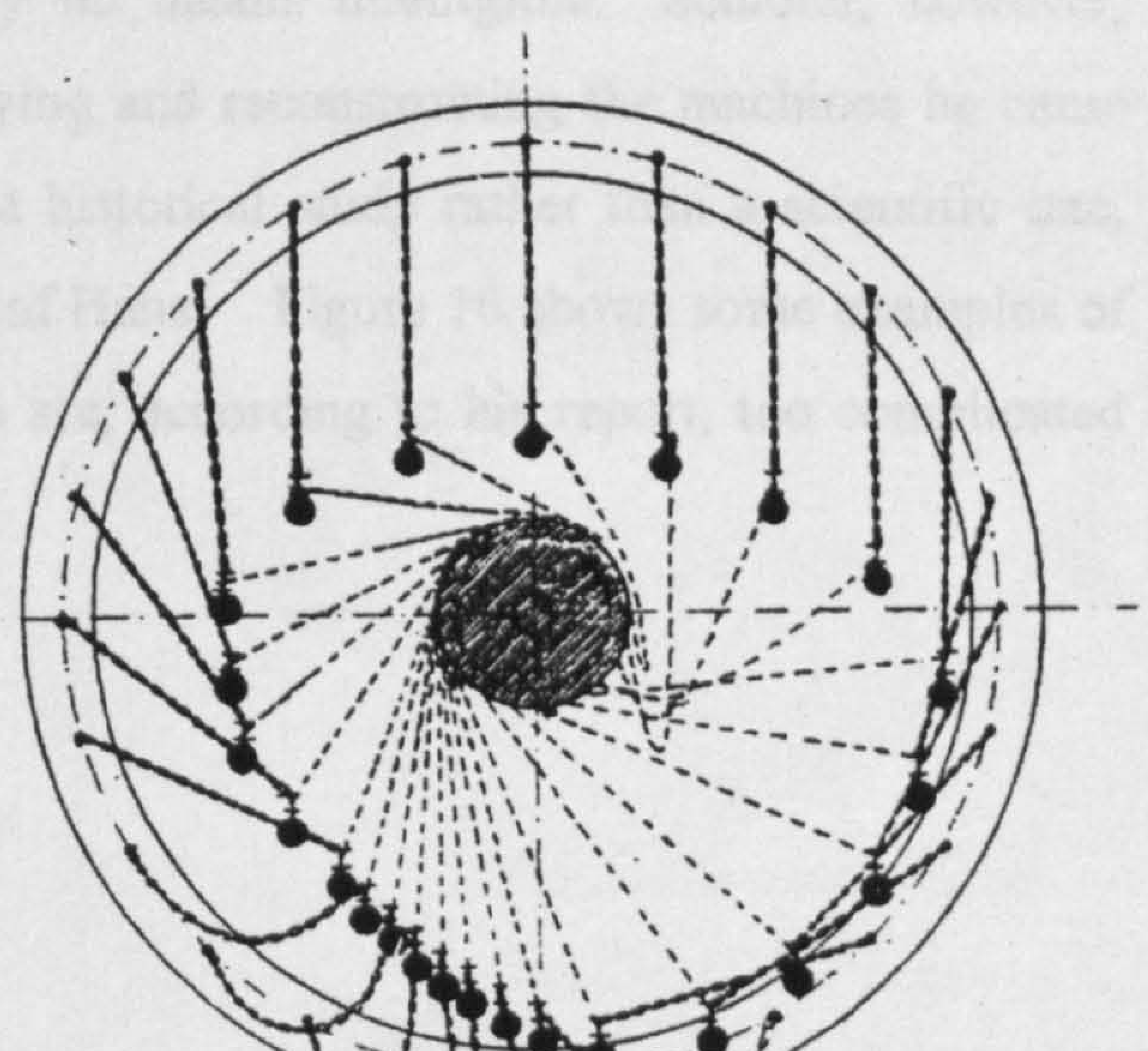

Figure (15)

2. Thorkild Schioler study

The study in the book 'Roman and Islamic Water lifting Wheels' by Schioler (1973) was not indeed devoted to examine in particular the mechanisms involved. It was in fact a historical representation of machines described in various manuscripts the author has accessed, and the machines that listed in Hans' work. The conclusion Schioler has drawn shows the difficulty in commenting upon such subject, he writes:

- "It is, in fact, extremely difficult to comment on such a chapter as Wheels which turn by themselves, but before we judge the authors too harshly, we should remember to whom those manuscripts were addressed. They were intended for Sultans, not for simple carpenter; and this may be one of the tendency towards sensationalism-the science fiction of those days-rather than towards realism".[3]

In his review of Hans' work on the perpetual motion, Schioler tried to match up some of the machines appeared in a number of the manuscripts he acquired with those of Hans. He reports that although the described machines in the manuscript are systematically arranged, the text is by no means intelligible.[4] Schioler, however, seems not to involve himself in modifying and reconstructing the machines he came across; so in a real sense his work is a historical study rather than a scientific one, which is why it appears inferior to that of Hans. Figure 16 shows some examples of the machines listed by Schioler, which are, according to his report, too complicated and incomprehensible.

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[3] Schioler, Thorkild (1973) *Roman and Islamic Water-Lifting Wheels*. Odense University Press. p.78.

[4] *Ibid.* p.74.

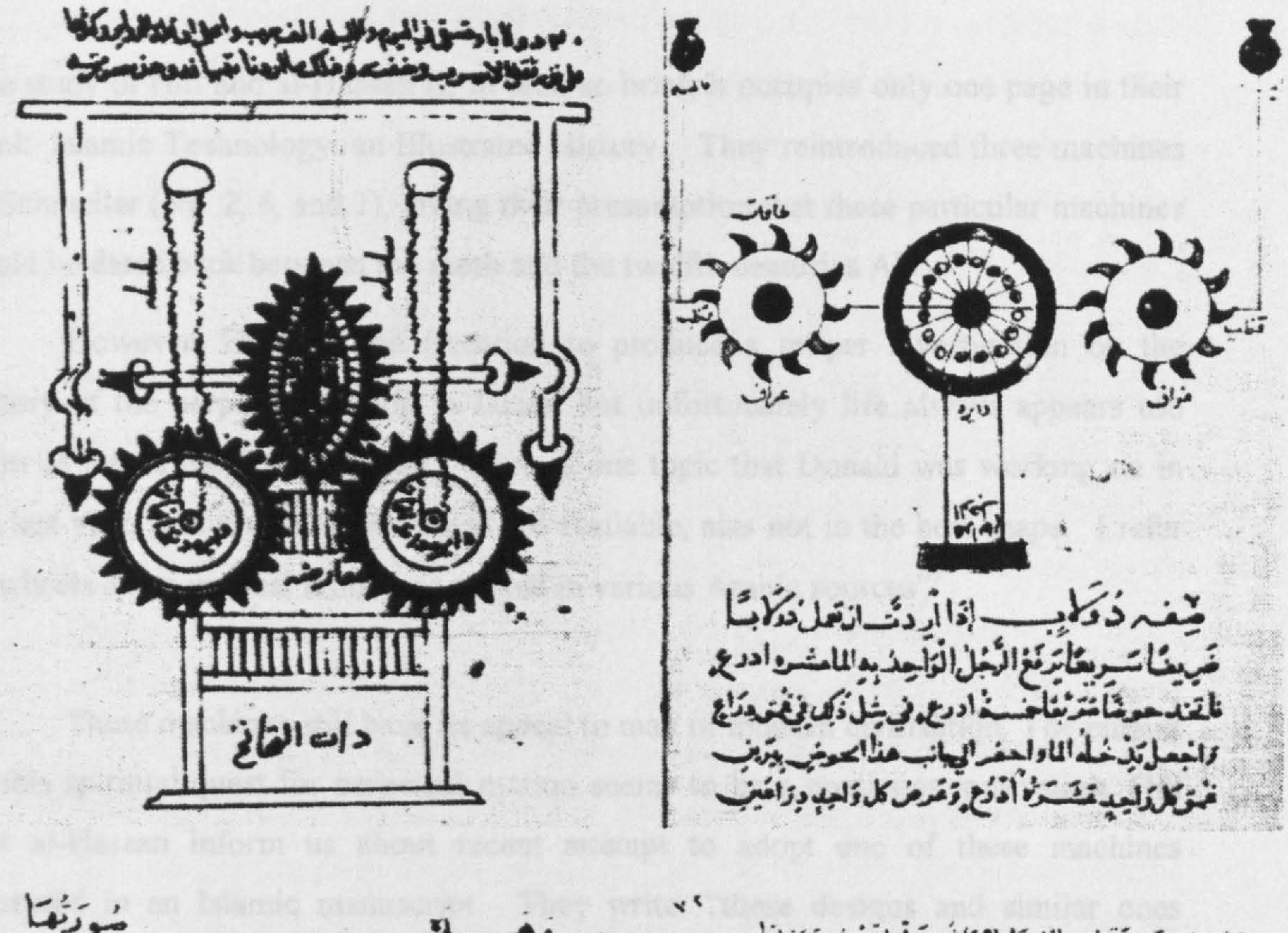


Figure (16)

Some of the machines Schioler listed inhis historical review of perpetual motion in Islamic manuscripts.

3. Hill and al-Hassan study

The study of Hill and al-Hassan is, in fact, so brief; it occupies only one page in their book, Islamic Technology: an Illustrated History. They reintroduced three machines of Schmeller (No. 2, 6, and 7), giving their presumption that these particular machines could be dated back between the ninth and the twelfth centuries AD.

However, Hill had the intention to produce a proper investigation on the history of the perpetual motion in Islam, but unfortunately life always appears too short as David King tells us that " there is one topic that Donald was working on in his last years and for which his notes are available, alas not in the best shape. I refer to wheels and perpetual motion as treated in various Arabic sources"[5]

These machines still have its appeal to man of modern civilisation. The pursuit of this spiritual quest for perpetual motion seems to be a continues motivation. Hill and al-Hassan inform us about recent attempt to adopt one of these machines appeared in an Islamic manuscript. They write: "these designs and similar ones continued to be of interest in Europe until comparatively recently; indeed, this last principle (machine 7 of Hans) was adopted by George Lipton in England only a hundred years ago"[6].

In his article 'Islamic Fine Technology and its Influence on the Development of European Horology', Hill provides us with some account on the perpetual motion. Here I have found it more appropriate to quote the whole paragraph concerned, since it is the only published work on this subject by Hill. He writes:

> "We now have to make an apparent digression, and consider a chapter called Wheels which turn by themselves, which is to be found in six different Arabic

[5] Hill, Donald R. (1998) *Studies in Medieval Islamic Technology: From Philo to al-Jazari -from Alexandria to Diyar Baker.* p.xvii.

[6] Al-Hassan, A. Y. And Hill, D. R. (1992) *Islamic Technology: An Illustrated history.* p. 71.

manuscripts. There are variations from one manuscript to another, but there are enough similarities to suggest that they all came from a common source. The devices have often been dismissed as unintelligible or absurd or both, but our written sources are not so abundant that we can afford to dispense with any document, however fanciful it may seem. Two devices, in particular, are worthy of attention. In one of these a large wheel has a number of S-shaved pipes, partially filled with mercury, fixed to one of its sides, in such a manner that when the wheel is at rest in any position it is statically in balance. The wheel is mounted on an axle, which also carries, at either side of the main wheel, a chain-of-pots wheel. According to the text, once the large wheel has been set in motion, it will keep on rotating because of the action of the mercury sliding up and down in the pipes. The second device consists of a pair of water-wheels driven through gears by the descent of two lead weights attached to ropes wound around the main axle of the machine. It is reasonably certain that 1 have given here the basic principles described in the two passages, although there are obscurities in the text and the accompanying illustrations add little to our understanding. Both concepts are, of course, nonsense - the first because there is no input of energy and the second because the descent of the weights is uncontrolled. It is assumed that this treatise was written for the amusement of courtly circles and not for practical application, but nevertheless it is difficult to understand why it was written at all. We can conjecture that the writer knew quite well what he was about and that he omitted certain essential components in order to safeguard 'trade secrets'. Weight is lent to this supposition by the existence of a practical machine, which combines the main principles of both machines - mercury escapement and weight-drive"[7].

[7] Hill, Donald R. (1998*) Studies in Medieval Islamic Technology: From Philo to al-Jazari -from Alexandria to Diyar Baker*. pp. 15, 16.

Comparative Discussion

From the previous review of the studies of the perpetual motion machines in the work of Muslim engineers undertaken by prominent engineers and historians, there are a number of points characterise the manuscript I have investigated.

Firstly, despite the fact that we know almost nothing about the author of the manuscript, his name and his life, we are at least informed about where he lived, his connection with the people who shared with him the same interest, and how critical he was about his predecessors' work. This is clearly presented in his comments on al-Jazari's work on the construction of the water-clock and the automata to whom he attribute his inspiration. The attempt to solve the enigmatic engineering of perpetual motion by the engineer dose not undermine his engineering credibility, as we have concluded in the first section of this chapter that the engineer was skilful and well acquainted. This can be realised from his acknowledgement and understanding of the work of the renowned thirteenth-century, al-Jazari, whereas none of the other engineers who designed perpetual motion machine did mention or acknowledge their predecessors. So we do not know who they really were, were they were engineers? or were they, as it is believed, were professional carpenters?

Secondly, it has been indicated by Hans, Schioler, Hill, and al-Hassan that all the manuscripts they studied suffered several defects. These mainly are the contradictions in describing a machine between a number of manuscripts, the intention to disguise certain components of the machine to preserve it secrecy, and the big contrast between the text and the drawing. This, in fact, is not the case in the manuscript *al-Riysala al-Qudsiyya,* in which we find an elaborate description of the construction of the machine and its mechanism, despite the absence of any drawing.

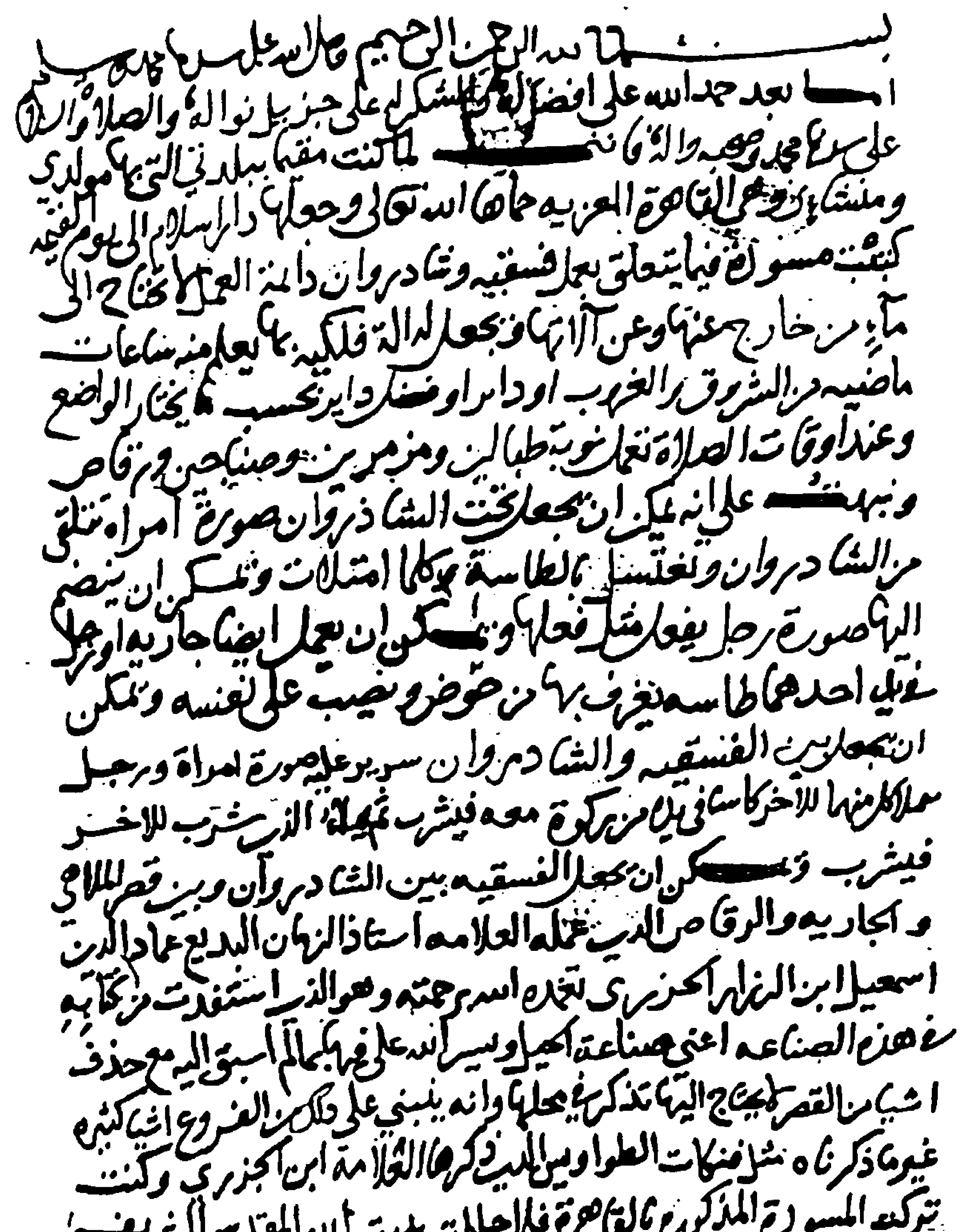
Thirdly, all the machines investigated by those scholars show a consistent trend to use the mechanism of gravitational force that is generated from the movement of fluids, especially mercury, and in other examples of weights. This mechanism was originally introduced by a Hindu astronomer in the fifth-century. The transmission of the idea of perpetual motion and its mechanism is discussed in Chapter four. The design approach of the machine described in the manuscript *al-Riysala al-Qudsiyya,* however, is completely different and diverse. The author, in this particular machine, intended to exploit the levering mechanism parallel to the falling-weight mechanism in such a complicated setting. He proposed that the sufficient force provided by the lever and the weight would create an equivalent overbalance to drive the whole machine indefinitely.

Finally, in comparison with the design of the other machines, the design of this machine appears to devoid from any exaggeration in size and description. In contrast some of the machines designed by other engineers supposed to be built in such large scale, as the wheel of one of the perpetual motion machines, which is investigated by Schmeller, requires twenty men to move it to be set in motion. The description of these machines in general was exaggerated in order to convince the reader that these machine are perfectly practical, which is not the case in descriptive text of *al-Riysala al-Qudsiyya's* machine. The machine I have examined measures approximately 30x120x120 centimetres; the diameter of its wheel does not exceed twenty-five centimetres. Furthermore the engineer of this machine did not try to be very elaborate in his description; he, however, was very rational and straightforward.

The Qudsiya Treatise
on Constructing a Cascade and a Fountain

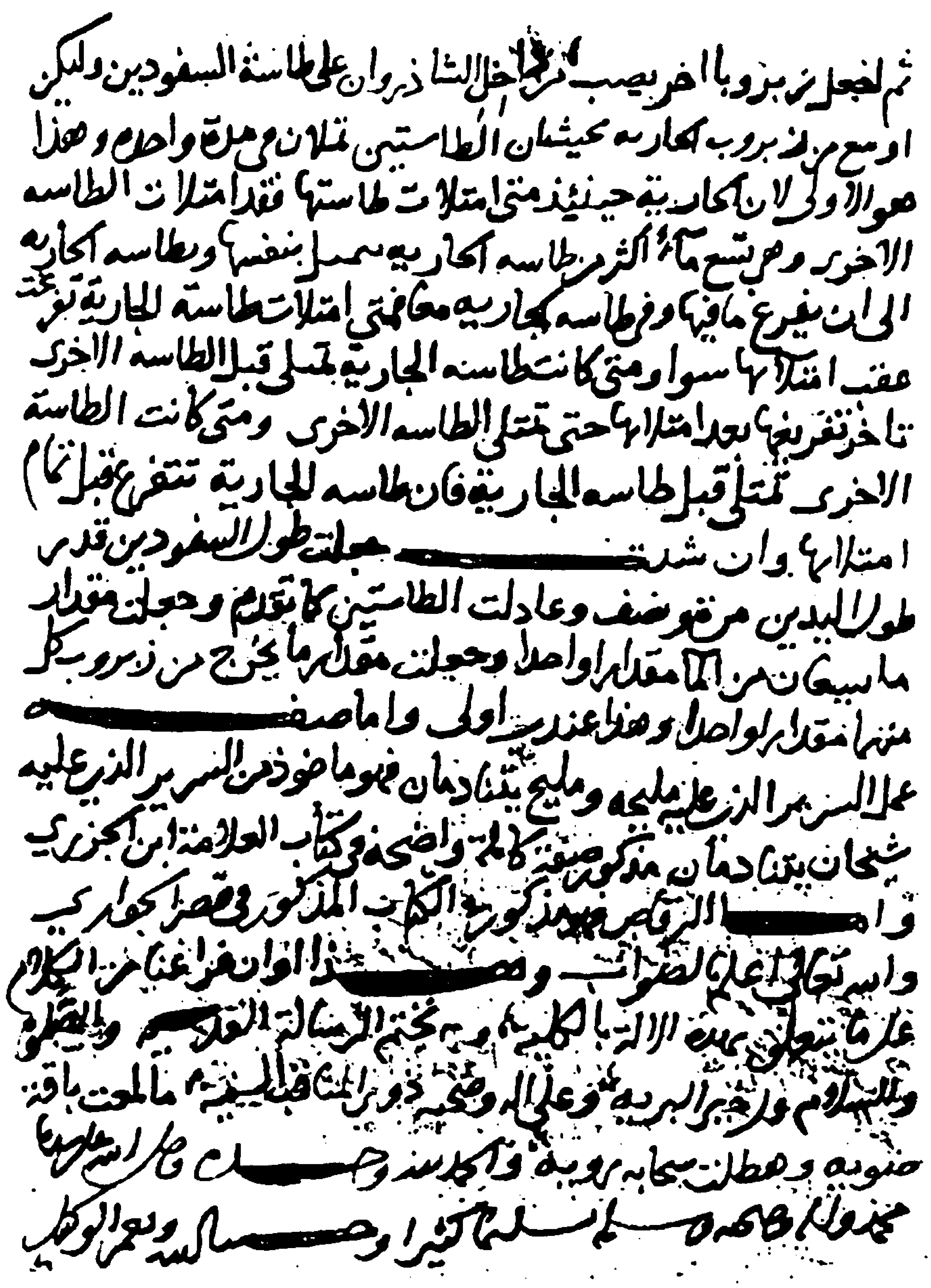
(Al-Riysalaa al-Qudsiya fi Amel al-Shadriwaan wal-Fisqiya)

(15th century)



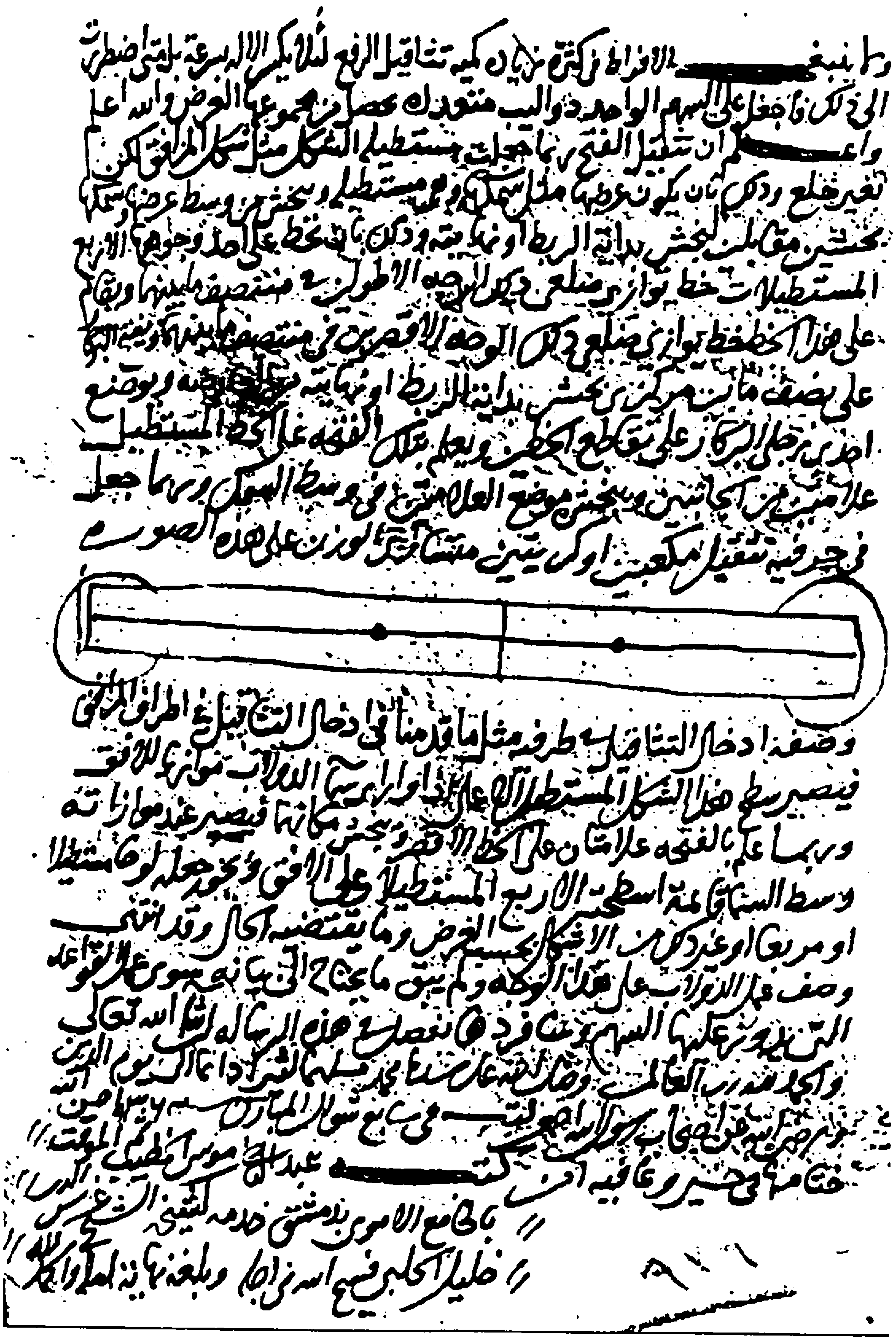
بسم الله الرحمن الرحيم صلى الله على سيدنا محمد وسلم
اما بعد حمد الله على افضل ... والشكر له على جزيل نواله والصلاة والسلام
على سيدنا محمد وصحبه وآله ... لما كنت مقيما ببلدتي التي هي مولدي
ومنشاي وهي القاهرة المعزية حماها الله تعالى وجعلها دار اسلام الى يوم القيمة
كنت مشغوفا فيما يتعلق بعمل فسقيه وشادروان دائمة العمل لا تحتاج الى
ما يأتي من خارج عنها وعن آلاتها وبجعل لها آلة فلكية بها يعلم منه ساعات
ماضية من الشروق والغروب او دائرا او ... بحسب ما يختار الواضع
وعند اوقات الصلاة نغمات نوبة طبالين ومزمرين وصناجين ورقاص
ونحو ذلك على انه يمكن ان يجعل تحت الشادروان صورة امراة تتلقى
من الشادروان وتغتسل بالطاسة ... امتلات ويمكن ان ينضم
اليها صورة رجل يفعل مثل فعلها ويمكن ان يعمل ايضا جارية او رجل
في يد احدهما طاسة تغترف بها من حوض وتصب على نفسه ويمكن
ان يجعل بين الفسقية والشادروان سرير عليه صورة امراة ورجل
مع كل منهما للآخر كاسا في يد من بركة معه فيشرب ... الذي شرب للآخر
فيشرب ويمكن ان يجعل الفسقية بين الشادروان وبين قصر للملاهي
والجارية والرقاص من الذي عمله العلامة استاذ الزمان البديع عماد الدين
اسمعيل ابن الرزاز الجزري تغمده الله برحمته وهو الذي استفدت من كتابه
في هذه الصناعة اعني صناعة الحيل ويسر الله علي فهمها ما لم اسبق اليه مع حذف
اشيا من القصر لم يحتاج اليها تذكر في محلها وانه ينبني على ذلك من الفروع اشيا كثيرة
غير ما ذكرناه مثل حركات الطيور ومثل الذي ذكرها العلامة ابن الجزري وكنت
تركته المسورة المذكورة بالقاهرة فلما حللت ببيت الله المقدس الشريف

The first page of treatise



ثم لنجعل زبزوبا اخر يصب في داخل الشاذروان على طاسة السفودين ولكن
اوسع من زبزوب الجارية بحيث ان الطاستين تملآن في مرة واحدة وهذا
هو الاولى لان الجارية حينئذ متى امتلات طاستها فقد امتلات الطاسة
الاخرى ومن تسع ماء اكثر من طاسة الجارية بمعمل بنفسها وطاسة الجارية
الى ان يفرغ ما فيها وفي طاسة الجارية معا فمتى امتلات طاسة الجارية تفرغ تحت
عقب امتلائها سوا ومتى كانت طاسة الجارية تملى قبل الطاسة الاخرى
تاخر تفريغها بعد امتلائها حتى تمتلي الطاسة الاخرى ومتى كانت الطاسة
الاخرى تمتلي قبل طاسة الجارية فان طاسة الجارية تتفرغ قبل تمام
امتلائها وان شئت جعلت طول السفودين قدر
طول اليدين من فوق نصف وعادلت الطاستين كما تقدم وجعلت مقدار
ما يسع الثمن من الما مقدارا واحدا وجعلت مقدار ما يخرج من زبزوب كل
منهما مقدار واحدا وهذا عندي اولى واما صفة
عمل السرير الذي عليه مليحة ومليح يتنادمان فهو ماخوذ من السرير الذي عليه
شيخان يتنادمان مذكور صفته كاملة واضحة في كتاب العلامة ابن الجزري
واما الرقاص فهو مذكور في الكتاب المذكور في قصر الجدر ك
والله تعالى اعلم بالصواب وهذا اوان فراغنا من الكلام
على ما يتعلق بهذه الالة بالكلية وبه نختم الرسالة العديمة والصلوة
والسلام على خير البرية وعلى اله وصحبه ذوي المناقب السنية ما لمعت بارقة
صنوبه وهطلت سحابه بروبة والحمد لله وحده وصلى الله على سيدنا
محمد وال وصحبه وسلم تسليما كثيرا وحسبنا الله ونعم الوكيل

The last page of the treatise



The last page of the manuscript

In the Name of God the Compassionate the Merciful
And peace and blessings of God upon our lord Mohammed

Praise be to God for all His favours, and thanks to Him for His generous giving. Peace and blessings upon our lord, Mohammed, his companions and his descendants. While I was a resident in my hometown, the glorious Cairo, where I was born and grew up, may God the Almighty bestow his protection upon it and make it a bode of Islam until the day of resurrection, I wrote down a draft on constructing a fountain, ***Fysqiya,*** *and a cascade,* ***Shadriwaan,*** *of perpetual motion type, which requires no external water source out of itself and its mechanical parts.*

An astronomical device, ***Aalla***[1] ***Falakyia,*** *is installed which shows the time remaining or past of sunrise and sunset, corresponding to the preference of the setter. A session by drummers, flute blowers, cymbalists, and a dancer goes off as prayer time is due. I have indicated that it could be possible to have a woman bathing with a bowl in hand; filling water from the cascade. It is possible as well to have a man in her company doing the same. Also, a female servant or a man fills water in a bowl from the basin, pouring it on him or on herself. Another possible thing to have is a man and woman sitting on a bed, each one of them filling a cup and handing it over to the other to drink. This could be erected between the basin and the cascade. Also it could be erected between the basin and the cascade or the amusement quarter and both the female-servant and the dancer, which idea was initially devised by the master of the era, the most innovative* ***Imaad al-Din Ismaiel Ibn al-Razzaz al-Jazari,*** *may God have ample mercy on him.*

From his book I have benefited in this Art, I mean the Art of the Ingenious Mechanical Devices, ***al-Hiyal,*** *and God has enlightened me with unprecedented ideas. Thus I have excluded unnecessary things from the amusement quarter,* ***Qaser al-Malaahi,*** *and this will be mentioned in due course. Upon these divisions lots of things are based, excluding what we have already mentioned, for instance the Peacock-water-clocks,* ***Fanikaat al-Tawaawiyys,*** *that had been mentioned by the*

[1] I have altered this term to *Aalla* [device] instead of *Dalla* [indicator], which dose not make sense, however, we find the term *Aalla* is repeated elsewhere in the treatise, so it is most probably a copyists mistake.

master Ibn al-Jazari. In Cairo I have left the draft, mentioned earlier, and when I took up residence by God's House, in Jerusalem,

al-Moqadass, *the glorious, the sublime, the exalted, I conferred with the one to whom my obedience is compulsive*[1]*, and to whom I shall never be able to pay back the great favours he bestowed upon me, till the day of judgement. He asked me, may God grant him support, to compose an operational description of the machine mentioned, and write it down in the form of a treatise. So out of His great blessing and favours then, given the blessing of the one I mentioned earlier [my patron] God Almighty inspired me with two great, simple, yet beneficial concepts which are much easier to adapt than that concept I had devised in Cairo; these concepts are supported by manifest evidence. I have made this treatise as a documentation, and I seek refuge in God from any mistake and error; and I have given it the title The Qudsyia*[1] *Treatise in Constructing a Cascade and a Fountain,* ***Al-Rissalla al-Qudsyia fi Amel al-Shadriwaan wal-Fisqiya.*** *By the blessings of God, this machine will appear in a strong state and perfect performance as an ideal concept in good design. Then I will explain its contents in very clear terms, illustrating its components when necessary. This with help and success from God to follow the right path, He is the most Generous, Merciful, and Forgiving. I have arranged it in three chapters.*

Chapter one

About the first concept:

Two square-bars, ***sahm,*** *are arranged, sized one span,* ***Shibr,*** *in length and two by two* ***joined-fingers*** *in width. On the first one a hole,* ***bakhesh,*** *is made on each end; that two joined-fingers a distance from the its edge. A penetrated hole is centred allowing a* ***finger*** *to pass through it. On the other side, one finger [width] down from the first hole, another hole is made, so the two holes shall not meet. Therefore, there*

[1] The author of the manuscript refers to his patron for whom he might have worked, however, his name is not mentioned in this treatise; but we find a reference to his name in the second treatise that deals with water-lifting devices. This will be dealt with in the discussion in the following chapter.

will be four penetrated holes in this square-bar, on each end of which there would be two holes. Then four round-bars, pen-like[2] *each of which is one small-span,* ***fiter,*** *in length are to be inserted forcefully into the holes. Then you prepare four cross-beams,* ***'arydaa,*** *each one sized one span in length and rounded-shape in one finger thickness with square-heads. Each of which is holed close to its edges into which each end of the four axes,* ***mihwaar,*** *is inserted making the four cross-beams parallel to the four surface of the square-bar, which comes to be called 'Cross-beams-wheel',* ***dullab al-'awaaryd.***

Then a bar, ***'adaada,*** *of copper or solid-wood sized two spans in length, two joined-fingers in width, and a finger in thickness. On the other square-bar, right in the middle of its length, a groove is made two joined-fingers in length, that in line with the width of the square-bar, and a finger in width aligned with the length of the square-bar*[3]*. So the bar is inserted forcefully into it and is cross-nailed. Then two holes are made on the top of the bar at the wide side leaving one finger space from the edge and another finger space between the two holes. The first is assigned for the axle,* ***mihwaar,*** *of the vessel,* ***ina'a,*** *which is fitted into it, and the rope that is connected to the 'Cross-beam-Wheel' is fastened to the other. The hole of the axle of the vessel has to be inclined towards the side at which the bar descends to fill up the vessel. This bar-wheel,* ***dullab al-'adaada,*** *is to be called the 'Vessel-wheel',* ***dullab al-ina'a,*** *as well.*

Then a bronze, ***sifer,*** *vessel is made, light in weight as much as possible, shaped in a quarter of a sphere; this has the capacity of half* ***ratle*** *of water, the Egyptian ratle*[1]*, and one finger width is to be left out from the vessel. A hole is made close to the rim of the vessel that is quite similar to the hole on the bar. Then a thicker axle connects the two holes, which is thicker than a thick copper-rod* ***mayil.*** *The two ends of the axle are rounded in the shape of round-headed,* ***falsyin,*** *so the*

[1] The name of treatise is derived from the city (*al-Quds*) Jerusalem in which the author composed this treatise.

[2] To differentiate between square-bar and round-bar the writer added 'pen-like' introducing to the reader a clear description. This is basically called in modern terms 'rod'.

[3] The depth of the groove is not mentioned, presumably it is made all the way through the square-bar.

vessel rotates very swiftly. On its convex side, outside of its bottom, a small piece of copper-rod is firmly attached. Then two bronze pots, ***qaadows****, are arranged, one of them has the capacity of half a ratle, while the other is one ratle, Egyptian one, and a finger width is to be left free from each pot. On the mouth of each pot, one finger width cross-bar,* ***'adaada****, ruler-like, is nailed, that is extended a little extra over its edges. Two holes are made on the edges of the pots into which the rope for lifting the pots can be inserted.*

The pot, perhaps, can be split in half by a vertical sheet or it can be a half-boat-like shape that is covered by a flat sheet on which the bar is fixed. Whatever the shape chosen, a piece of thin copper-rod, ***mayil****, is firmly attached to its lower part. Its positioning is determined so that as the bottom of the pot hits the surface of the water, the rod at the same time, hits the upper level of the tank, causing the pot to tilt on its side and be filled with water.*

Then a round axle, ***mihwaar****, made from solid wood or from Sycamore,* ***jummaze****, wood is taken, which must be free from rottenness and shakes, one span in length and one finger-length in diameter. In the middle this axle, a groove,* ***nahr****, one finger or less in width, as well as in depth, is carved-out. This groove and all the others are made according to the job requirements. Then two grooves on one side of the axle are made parallel to the two holes on the cross-bar of one of the two pots. On the other side, two grooves are carved out parallel to the holes on the cross-bar of the other pot.*

Then four ropes are taken, the type that is known in Egypt by ***al-Rummaniyyat****[2] ropes, each of which is four spans in length, or a bit more. Each end of which is inserted into a hole on one of the two cross-bars of the two pots, making a knot outside the cross-bar towards the pot side. The other end of each rope is fastened to a staple,* ***razah****, on the groove that is parallel to the hole on the cross-bar. This axle is called 'Pot's axle',* ***mihwaar al-qawaadyis****. Then take a wooden tank,* ***hawod****, or even better a brass one with a rim,* ***dayiar****, attached to it. On its border an embankment-like is projected around the tank, similar to that used for the pots of the*

[1] The Egyptian Ratle is a weighing measurement that equals 449.25 grams
[2] The author mentioned this particular type of rope to which I could find no reference in terminological sources of the time.

Water-wheel, ***saqiya****, in Egypt. A wooden board divides the tank into two sections; one of them is one-third whilst the other is two-thirds. The one-third section is at the side of the small pot and the two-third section is at the side of the big pot. The outlet of the big section is fixed to a pipe which is connected to the cascade, the fountain-jets,* ***fawawear****, of the basin, and to the astronomical device, this will be explained later, God willing. The, outlet,* ***masraf****, of the small section is connected to a pipe, which reaches the mouth of the vessel that is attached to the bar as this vessel reaches its maximum height. This tank is called the 'Pot's Pouring-out-Tank',* ***Hawod tafryigh al-Qawaadyis****. Then take a tank, one span in width, one and half spans in length, and its depth equal to the height of the two levels of the basin. This tank is to be placed on the floor of the housing,* ***sowndoque***[1]*, in a position from which pots fill up as they have been released from the axle and whatever spills out of these pots while pouring into the tank falls back into it. To the bottom of this tank, a pipe is connected to the lower level of the basin; this is to be called the 'Pot's filling-up-Tank',* ***Hawod myl' al-Qawaadyis****. This tank is to have two levels; the upper one is deep enough for full immersion of the big pot. In the middle of the floor of this upper level,* ***tabaqa****, a finger-sized hole is made that allows water to run into the two levels.*

Then a square-tank is made, its axis being one and half or twice the pot's diameter, and the same as the 'Pot's-filling-up-Tank' in depth. The outlet is made at the bottom, which is connected to the lower level of the basin or to the 'Pot's filling-up-Tank'. But if you make its outlet on the top that is connected to other parts of works then its depth has to be four fingers. This is to be placed on the housing floor, for an outlet is to be located at its bottom, which penetrates the lower level of the basin or the bottom of the 'pot's filling-up-Tank'[2]*. However, you may raise up this tank and bring it in line with the bottom of the upper level of the basin where it is connected to the inclined fountain-jets that stand opposite each other along the four edges of the basin, as we will describe in the making of the basin. Or you may raise it*

[1] The housing, ***sowndoque***, which means literally in Arabic 'box', here it contains the machines of the device.

[2] The introduction of the another possibility of setting-up this tank is utterly incorrect considering the surface level of liquids in vessels of varying shapes. So this tank has to be raised up to the level of the other tank. Most probably the four fingers measurement mentioned is for the depth of the outlet not for the depth of tank itself.

a little higher, where the maximum rise is two spans from the ground; so its water is to be diverted toward the astronomical device, the drummers, the dancer, the bathing woman or such like, as we will describe in the appropriate place.

Then the 'Pot's Pouring-out-Tank' is erected on either beams or bases between which and the bottom of the upper level of the 'Pot's Filling-up-Tank' four spans space is left. On its edge that is toward the 'Pot's Filling-up-Tank' the Pot's axle is erected higher up from its rim by one finger width. This is positioned on two stable bases with two beads, ***kharazh****, in which two pieces of copper-rod are centred in each of its circular sides. This procedure is to be repeated with the 'Beams-wheel' and Bar-wheel. Then erect the 'Beams-wheel' with its upper beam parallel with the concavity of the 'Pot's axle' leaving two fingers or less space between it and the far end of the tank. Then you erect the Bar-wheel in which the centre of the cross-bar[1] of the bar is vertically beneath the axle of the 'Beams-wheel'.*

You are free to have it lifted up or lowered down, though its maximum rise is determined by the highest-reaching-point of the vessel that comes in line beneath the outlet of the 'Pot's Pouring-out-Tank' which pours into the vessel. Here I do not assign it exactly to be underneath, but more or less in line with it, and its maximum descent is determined by locating its tank on the housing floor. So as the vessel's projection, ***shathyyia****, passes above it and hits the cross-piece of this tank, it is poured out. It is alright wherever in between these you do erect it, providing that you erect its tank where the projection of the vessel hits the cross-piece of the tank so that it pours its contents into the tank.*

Then you allocate three ropes, ***rummaanyyiat****, one of which equals the length, or is longer than the pot's ropes. There should be enough length to connect the 'Beams-wheel' and the pot's axle. Then you tie-up one end of this rope to the middle of one of the four wheels' beams and then it is wound around them. The other end is connected to a staple inside the middle groove on the Pot's axle, which is to be rotated till the mentioned rope is completely wound around it and the pots are raised up to the point where all their contents are poured out into the 'Pouring-out-Tank'.*

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[1] Here the author introduced another term (*'adaada*) for the bar-wheel when he literally described it in the beginning as a bar that is nailed to a squared-bar.

Another rope is allocated, the same length as one of the pot's ropes, one end of which is tied to the lowest beam on its free part that is not parallel to the [bar-wheel][1]. On its other end an empty pouch is attached.

Then another similar rope is tied up to the hole of the bar that is freed from the vessel, by inserting it into the bar and making a knot in the hole on the cross-bar of the pot. Its other end is tied up to one of the wheel's beams. This rope is to be wound around the 'Beams-wheel' on the mentioned part until the bar is raised up to its maximum height. This bar should be a little inclined to the direction where it descends down after its vessel being filled up.

It is possible, however, to exclude this sort of setting by placing a peg in the hole of the vessel instead, which is projected from the direction of the bar where it descends as its vessel being filled up. Then a hole is made on the peg end, which is parallel to the breadth of the bar. A cross-axle connects the hole and the vessel, on which the vessel rotates very swiftly; one finger gap is left between it and the lower beam in the wheel[2].

This winding-up is set as the Beam's wheel rotates in the opposite direction; so the winding accordingly is released until the pots are lowered down to reach the tank from which they fill-up; meanwhile the bar descends to its lowest point. If this is to happene, then the pouch's cord is wound up accordingly until it reaches the maximum height. Then the pouch is filled with small stones, ***hassa****, little by little till the pots rise up rapidly to its maximum height where they pour out their contents. In the meantime the vessel rises to reache its maximum height.*

Notification, *it is essentially important that there should be one finger-size free space between the bar when it reaches its maximum height and the lower-beam when its rope[3] is fully wound around it. This is to be taken in consideration all times.*

[1] In the text it reads [..is not parallel to (***dullab al-qawaadyis***) pot's axle...] this is incorrect perhaps due to the close similarity between the two words in Arabic, which is why it was very likely misprinted by the copyist. Therefore, here I have altered it.
[2] This setting of the vessel contradicts the previous setting in which the narrow edge of the bar is vertical in this setting it is horizontally positioned. Both settings are workable, however the first one is more efficient and simpler.
[3] The text refers to a cord (***khayyit***) instead of rope; therefore I have altered it to match the previous description.

When you need to lift up the Bar-wheel higher than this then you raise up the Beams-wheel above the level of the Pots-axle accordingly. The maximum lift, however, is set as the cross-bar of the bar[1]*,* ***'aryydaat al-'adaada****, comes in line with the bottom of the Pot's-pouring-out Tank, which we mentioned earlier. There should be a finger width between the lower edge of the beams and the cross-bar of the bar.*

Whenever you need to lower down the Bar-wheel much more, then you should lower down the Beams-wheel respectively. One finger space, as we mentioned earlier, should be kept between the lowest beam of the Beams-wheel and the bar as it reaches its maximum height; providing that the Bar-wheel does not accede its maximum falling. We have stated that its maximum falling is determined by positioning its tank on the housing floor, and its height away from its tank is determined by the reach of the bar at the very bottom hitting the cross-piece of the tank when the vessel is poured into the tank. But one additional condition is required in terms of the lowering. That is if the Cross-beam-Wheel is lowered below the level of the pots-axle then the rope between them will strike the Pot's-pouring-out-Tank and this would impair it. Therefore, a pulley is needed which should be suspended between them above the tank to prevent the rope from striking the tank or its rim, although the need for this in lifting is more than lowering, God knows best. Then you may substitute the pouch with an equal weight of lead.

Notification, *It might be necessary to have lots of water because of the large number of boats, lion's-heads of the cascade, and other applications which are connected to the water produced from the basin and the cascade. So expand the pot's axle, multiply the pots, widen the Pot's-pouring-out and the Pot's-filling-up Tanks, enlarge the vessel and its tank, and make the falling-weights the same as the pots in number. And God knows best.*

[1] The author used again this confusing term for describing the square-bar mentioned in the beginning by calling it (***'aryydaat al-'adaada***) the cross-bar-of-the-bar that has the vessel attached to it, mentioned the previous page. The change in the term perhaps was due to the conversion of individual parts into a new formed component in the machine. Whatever the reason might be, it leads to confusion.

Then make a pipe from the small section of the tank that gets to the mouth of the vessel as it arrives at its maximum height as previously mentioned; and another pipe[1] *that is*

passed into the mains of the basin and the cascade. It is very obvious, as you know from the a fore mentioned, that if the vessel was at its very maximum falling then the ropes of the pots to have to be released allowing the pots to sink into the tank to be filled-up. So the falling-weight's rope is fully wound around the Beams-wheel. This falling-weight is primarily measured according to the counter-weight of the pots and the bar, as the vessel remains empty. Then the falling-weight pulls the pots up to the axle as well as the bar up to its maximum height; though the centre of vessel stays vertically beneath the pipe that is connected to the Pot's Pouring-out-Tank, into which pots empty out their contents. As the falling-weight comes to its very maximum falling, so all its rope is released from the beams and the water is poured out from the small pot into the small section of the tank passing through the pipe to pour into the vessel. Then the vessel unavoidably becomes heavier and is adequate to exert heaviness [force]; this because it is on a circumference of a circle that is four times bigger than the circle of the falling-weight[2]*. So it pulls down the bar rapidly till it comes to its very maximum falling where the projection of the vessel hits the cross-piece of the tank, causing the vessel to empty out its water. In the meantime both the pots and the falling-weight come to their maximum falling when the pots fill up as the vessel pours out, consequently the vessel becomes lighter and the falling-weight pulls up the pots and the bar with its empty vessel until both reach their maximum height. This process is continual.*

The water, however, that has been emptied out from the vessel return either to the Pot's filling-up-Tank or to an application that terminates at the lower level of the basin. This is because any setting of the applications is to terminate finally at that

[1] This pipe has to be diverted from the big section of the tank into which the pots pour their contents.
[2] The author has based the concept of counter-weight between the falling-weight and the filled-vessel on a mathematical calculation which is in fact unclear. He refers to the fact that the circumference of circle on which the vessel moves round is four times greater than the circumference of the of circle the falling-weight. That is why he suggests that the force exerted is consequently adequate to pull up the falling-weight to its maximum-height.

level, which is connected through a pipe to the lower level of the Pot's-filling-up-Tank.

The water flows from the big section of the tank into the mains of the fountain and cascade, and from there into the upper level of the basin and down to the lower level and finally to the lower level of the Pot's-Filling-up-Tank. This process is continuous. If there is another pipe that is linked to an astronomical device or any other applications, then its outlet is connected to the lower level of the basin, as mentioned earlier.

Continuation

It is important to have a strainer, ***misfaat****, at the outlet of the basin's main, and another one at the head of the pipe that water passes through it from the lower level of the basin to the Pot's-filling-up-Tank. Another two strainers are also necessary, one at the head of the small section's pipe and the other at the pipe head of the big section of the pot's-pouring-out-Tank.*

It is also important to fill up the basin with water until both lower and upper levels are full, and at the same time, the two ground tanks are filled-up as well; I mean the Pot's-filling-up-Tank and Pot's-pouring-out-Tank, and also the main that is connected to the basin and the cascade. Then you initiate the operation.

A regular check has to be undertaken on the pipes, to ensure that any leakage would be fixed very quickly by lead soldering. The pipes that connect the two ground tanks and the lower level of the basin are made to be dismantled and assembled, so the housing and the basin could be moved separately whenever needed. This is to be applied to all applications connected, so all pipes that deliver and discharge the water to and from can be dismantled and assembled, as we explained. The constructing of the basin is to follow with its fountain-jets and cascade, as well as other applications in the third chapter. God knows best.

Appendix*, on the top of the housing, a platform is fixed on which firm bases are erected that support the top tank, the axle, and the two wheels. A cover that is easy to displace and replace covers the housing that contains the wheels, ground* *tanks, and the bases. This excludes the pots-wheel and the upper tank, which are to be left uncovered because it is this sort of things, which is a ravish to the eye and such a pleasure to watch. But it could be possible that the Beams-wheel is raised above the level of the pots-wheel, especially in case of the second option, then the whole machinery ought to be is completely covered. However, the pots-wheel could be left uncovered if the Beams-wheel does not rise above it. It is possible to arrange a matching cover on top of the first one and also easy to displace and replace; God knows best.*

Chapter two

About the second Concept

This concept is the same as the previous one except in three conditions.

- ***The first condition:** the tank is to be undivided with a single pipe that pours into the vessel. Another thin pipe could be fixed to the tank that delivers the water to an astronomical device or another application, excluding the basin and the cascade.*
- ***The second condition:** the square-bar, the axis, of the Bar-wheel is to be divided into three sections. Two bars are joined at the dividing lines of the square-bar, as previously explained, and both bars have no extra cross-bars attached to them. One of these bars has a hole at the top into which the rope is inserted that was initially inserted into the hole of the bar[1], which is free from the vessel. The rope is knotted in the bar's hole and the cross-bars of the pots. Several holes are made in the other bar along its length. Then, one end of the axle is round-headed, which is to be connected to the vessel's hole and the bar's hole. The work is examined by suspending the porch on the falling-weight's cord as mentioned earlier. The vessel is to be attached to hole after hole on the second bar that has no rope; proceeding in the attachment of the vessel from the very top hole to the next one and then to the next and so on until the machine is set in motion. Then*

[1] It reads in the manuscript ('arydaa) cross-bar, which is incorrect therefore I have altered it to ('adadaa) bar instead hence the writer has refer to the construction principles in the first concept.

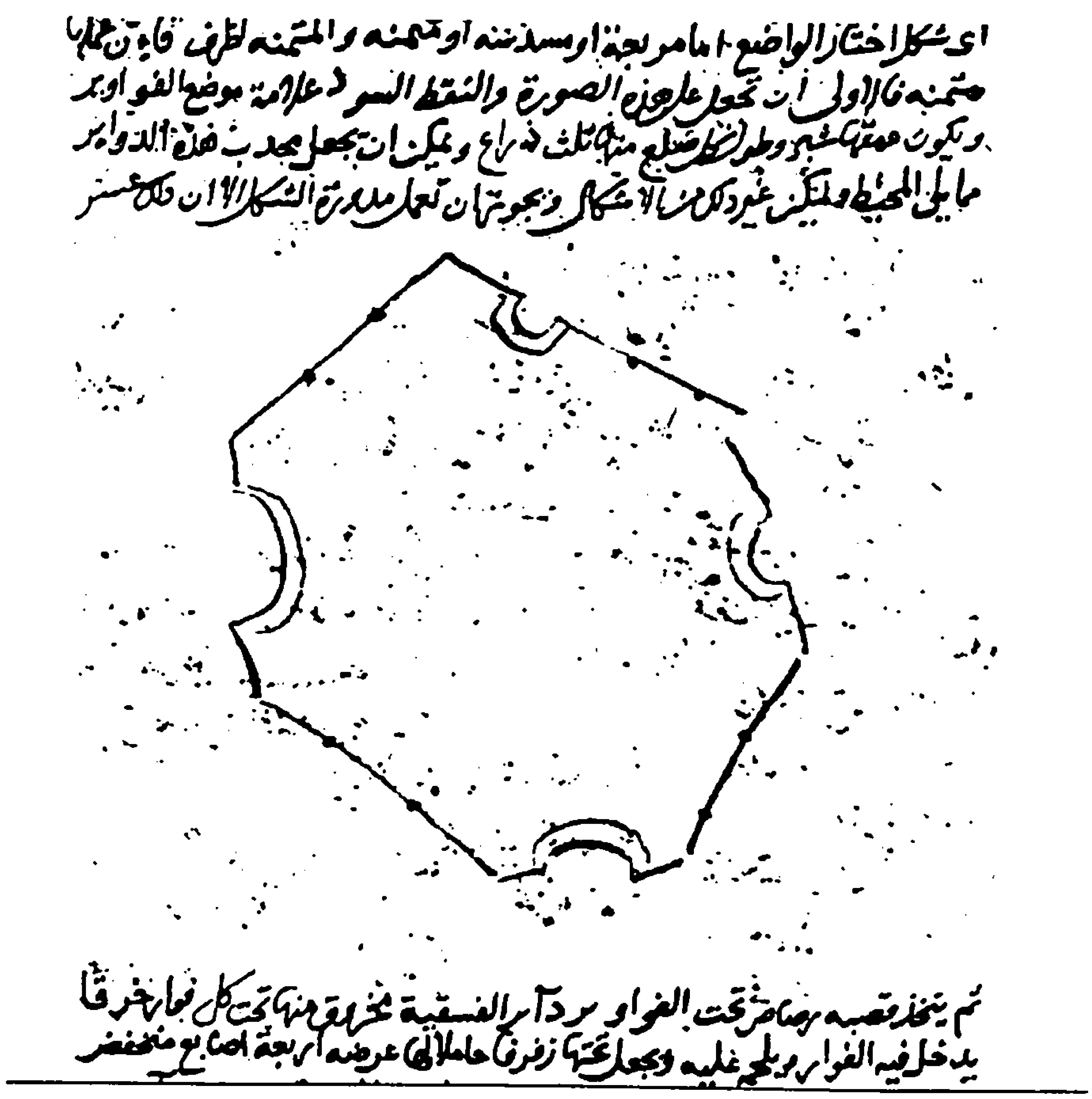
the other end of the axle is round-headed, as was explained in the first chapter. ***Notification:*** *Whenever you bring the vessel down, less falling-weight is needed. The right setting of the porch is when it pull-ups the pots and the vessel without slowness. As the falling-weight becomes lighter then the vessel descends, which is necessary due to the shortness of the bar on which the vessel is. As you shorten the bar then the Tank of the pouring-out vessel is raised, consequently the water of the cascade rises as well as the water from the fountain-jets. As this tank is more raised, the projected water rises up accordingly. As the vessel is set to the right hole, then cut off the part next to it of the second bar, although the bar that has the rope on it remains intact.*

- ***The third condition:*** *the vessel should have the capacity of water that is equal to the capacity of all pots, leaving one finger width free-space. It is obvious that of the two concepts,* ***the first one*** *requires an elongation of the bar's vessel, shortening and lightening of the vessel in order to fill less water in it and keep the rest for the basin and the cascade. As the bar is elongated, the little water in the vessel exerts the weightiness rapidly. The water in the vessel in the first concept was not intended for itself, but was intended only to drag down the falling-weight. Although the water that is poured out from the vessel is not intended for its own, the only benefit would be, in general, that the bar of the vessel is to be elongated as the Pouring-out-Tank is lowered down.* ***The second concept*** *requires the shortening of the vessel's bar, allowing the Pouring-out-Tank to rise, and also the enlarging of the vessel; as the bar becomes shorter, then more water is needed because the falling-weight would not be pulled up unless there is much water. This is also necessary because of the water that goes to the basin and the cascade, which is basically the tank of the pouring-out vessel. The first concept is superior to the second considering that the water from the fountain-jets and the cascade are much higher than the second concept. However, the second concept, is superior from the aspect that all the water goes to the fountain-jets and the cascade, so the volume of the water is much greater. So the water is higher in the first one and in the other it* *is more plentiful. To me, the first concept is utterly superior because the water in it can be expanded by increasing the pots and the water that the vessel receives and empties out into its tank. This it can benefit the upright fountain-jets, the astronomical device or in any other similar applications, those which are useful. The choice rests with the setter as to which he favours; and God knows best.*

Chapter three:

Making the basin and the cascade

A basin is chosen in any shape the setter favours, whether it be square, hexagonal or octagonal, although the octagon is more exquisite. If he made it octagonal then it is preferable to do it as in this illustration where the black marks indicate the fountain-jets. The depth of the basin is one span and each edge is measured by a third of an arm, ***thyra'****.*

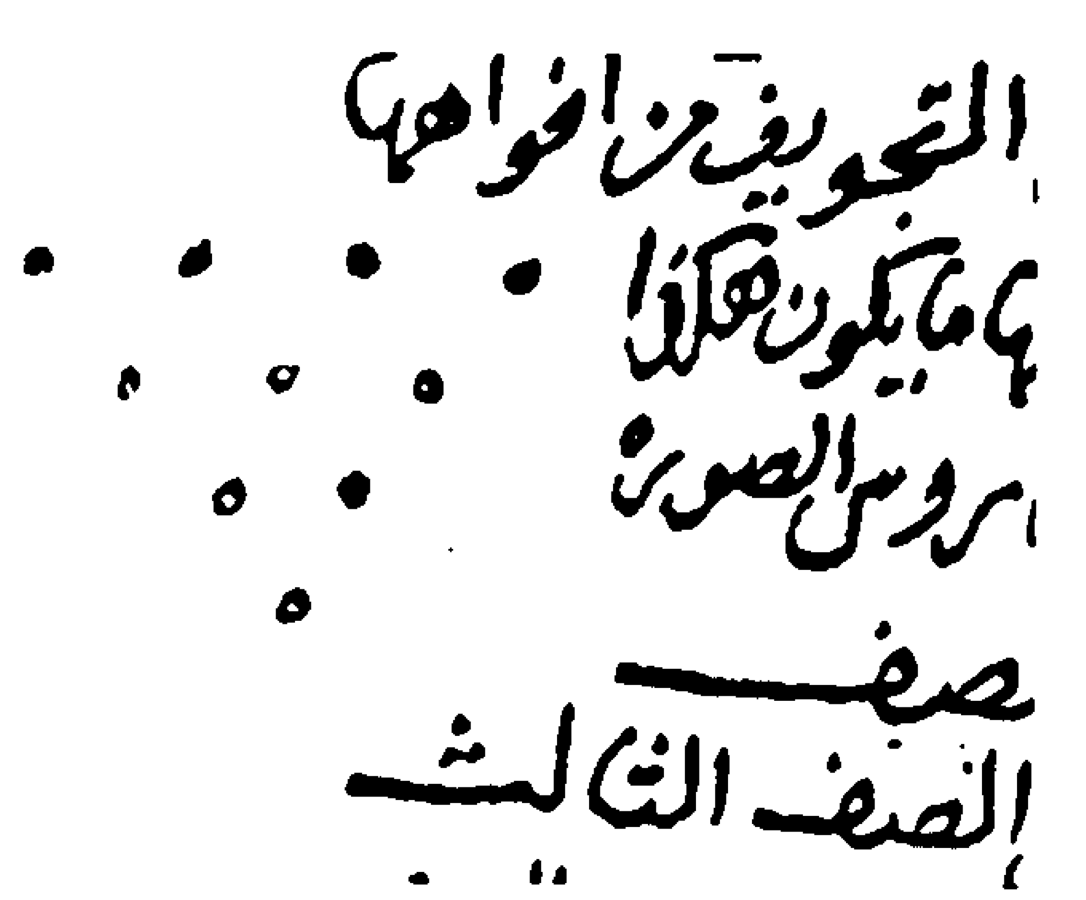


The concave of these circles is orientated towards the circumference. However, it could be made in other shapes; and also it is possible for it to be made in a round shape, although this would be difficult[1].

A lead-pipe is arranged beneath the fountain-jets all-round the basin, on which a hole is made, aligned with a fountain-jet that is inserted into it and then soldered. Beneath this pipe a ledge, ***rafraf****, four fingers in width, is made to hold it and is measured down from the top of the basin by three joined-fingers. On the top of the basin is another ledge to cover it, with the same number of holes as there are fountain-jets, each fountain-jet is inserted into a hole of its own; then the space between the ledge and its cover is covered all the way round the basin by wooden panels. It is up to you whether you make this cover all the way down to the bottom of the basin, or confine it to just the ledge. You ought to know that the ledge and its cover are the upper level of the basin and the rest is the lower level of it. All fountain-jets should be slightly inclined toward the centre of the basin to make their emission fall back into the basin. It is possible to have on the edge of the ledge inclined jets connected to the round-starched pipe or another pipe that is located within the ledge.*

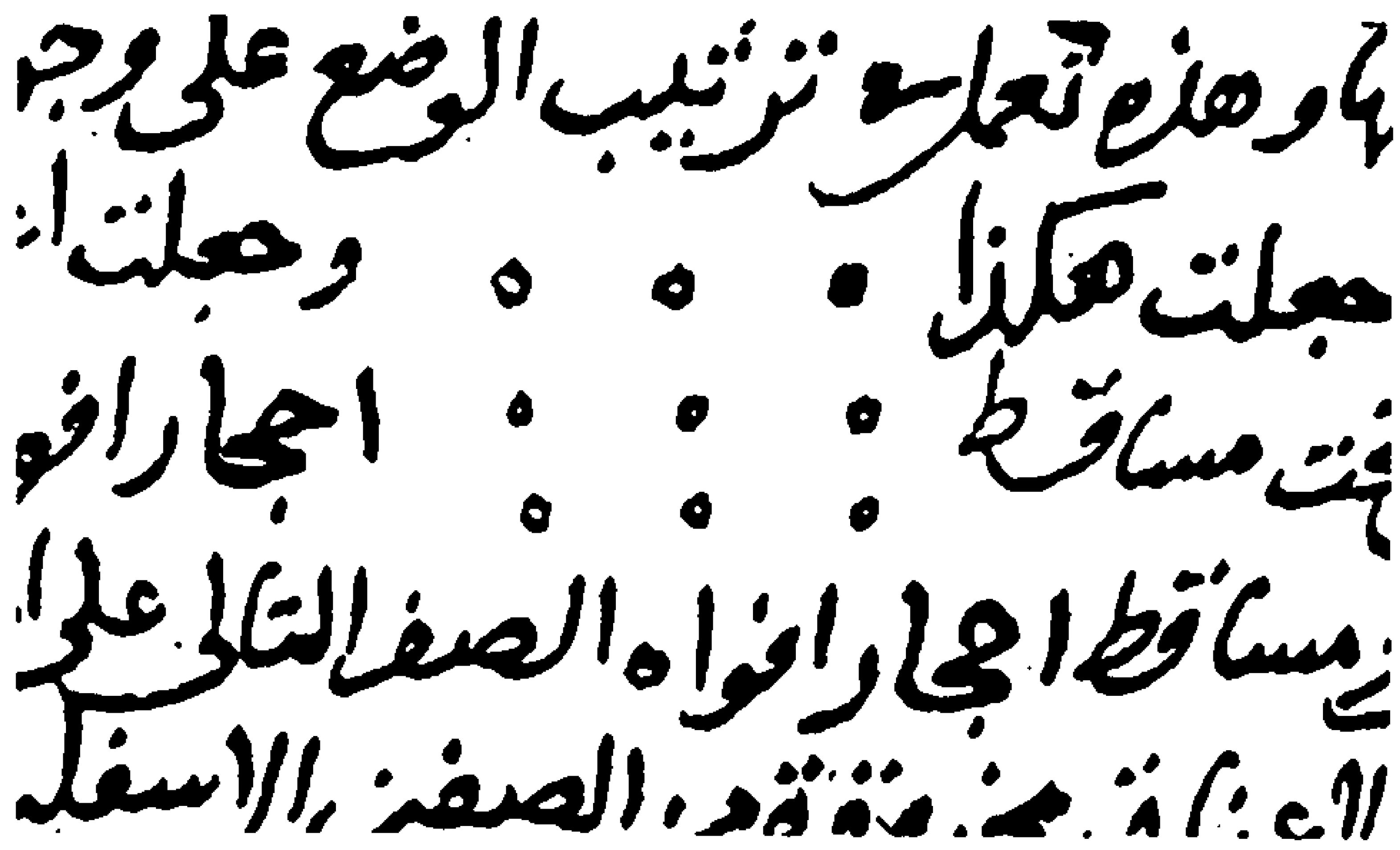
Description of making the cascade

Make on the middle front of the housing holes to which you add animal heads; for instance lions, hyenas, gazelles, birds, and snakes with a cavity all the way from their mouths to their necks. These are set in different arrangements; some of them like this:



[1] The last two sentences refer to the first drawing shown, which is a very crude plain drawing of the octagonal basin suggested by the writer. We do not know how the original drawing by the writer compared to this, which is drawn by the copyist.

Or it could be arranged like this



Make the necks of the heads vertically beneath the mouths of the first row, and the mouths of the second row perpendicular with the necks of the third row. The necks should be holed on both the last two rows, allowing the water to descend from the first row into the holes and the necks of the second row; and to descend from the mouths of the second row into the necks of the third row. This arrangement is to be made as the water has been insufficient due to the small size of the machines or to the big number of applications which require enough water to operate; that you will come to know, God willing.

Then make a slab of marble on which gold leaves are glued. The top of this slab is fixed to the housing and its bottom is projected one span away from the front-side of the housing. On both of its sides, make two elegant columns from gilded marble, ***saathej***[1]*, and coated wood with dissolved sandarac,* ***sandarows****, as it is known in common cascade; this is to be embellished according to the setter's preference.*

Underneath this slab, a wooden tank or wooden channel one span in width is arranged, which terminates at the inlet of the basin. It is also necessary to have a tank for this channel so that what falls out of this slab goes into the tank. A pipe for

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[1]The word here seems to be incorrect, I could not trace any relevant meaning in Arabic dictionaries, and most probably it is a copying error. Nevertheless, this word has no significance that might affect the description.

the tank is constructed which passes from the tank to the Pot's-filling-up-Tank. Its end is slightly projected from the front-side of the housing.

There is a hole in the tank through which this pipe passes, not too tightly, or too loosely. Then a tank is constructed, half span in depth, which is to be called the reservoir, **al-hasyl,** *and is erected beside the inner-side of the housing's front. If you applied the first concept then align it with the Pot's pouring-out-Tank. However, if you applied the second concept, then bring it in line with the Vessel's-Pouring-out-Tank, and make a pipe that passes from the top of one of the two tanks to terminate at the top of the reservoir. At the bottom of this reservoir make two holes, one of which is connected to a pipe which is parallel to the housing's front, descending on the inside till it comes in line with the fountain-jet's pipe. Then bend its end to slightly project it from the housing-front at the side of the cascade. This pipe is connected to the fountain-jet's pipe by another pipe, which is to be easy to be dismantled and assembled. If there is more than one pipe inside the ledge, then make this pipe pass through a hole into a fine tank that is aligned with it inside the ledge.*

From its bottom you can branch pipes out as much as you want. Probably the pipe of the inclined fountain-jets can be connected to the Vessel-pouring-out-Tank through another pipe. A second hole is made on the water-main which is linked to a wide pipe that has as many holes as the number of the animals' mouths that are on the cascade. Each pipe which is linked to an animal is connected to a hole on this wide pipe. This work would reveal to the explorer all facts, although the work will be eased if you apply these principles; and God knows best. It is possible to have a dome set on columns[1] *in such an arrangement where it would not be splashed by the fountain-jets; and God knows best.*

[1] This description represents a miniature Pavilion; from the entire arrangement the author tried to create a full scenario of water-features within the architectural form.

The Fountain Design
in the Work of the First Engineers

Banu (sons of) Musa

(The ninth century)

The Authors and their Book.

The ninth century was a golden age of Arabic science and technology; during the Abbasid dynasty (750-1258 AD) the Islamic civilisation was at its apex. Caliph Harun al-Rashid at that time was celebrated for his patronage of science and art, however, he was overshadowed in this respect by his successor al-Ma'mun.

The Islamic Arabic civilisation produced a number of world's geniuses, the pioneers of science and technology. Muslim scholars were far in advance of their contemporaries in other parts of the world. Among the most distinctive characters in intellectual life in that era were the three brothers: Muhammad, Ahmad, and al-Hassan who were called Banu (sons of) Musa.

In Baghdad, during the most glorious days of the Abbasid period, at the order of the Caliph Al-Ma'mun (reigned 198-218 AH. /813-833 AD) an academy of science known as *'Bayt al-Hikma'*, House of Wisdom, was established. The most serious activity carried out at this Academy was the translation of the original Greek philosophical and scientific works. Al-Ma'mun made great efforts to obtain valuable Greek manuscripts, for which purpose he sent missions to the Byzantine emperor. The translations into Arabic of these manuscripts were conducted at his order.

The House of Wisdom, *Bayt al-Hikma,* had a great library and an observatory. It is believed that it was the greatest scientific establishment of its kind since the introduction of the Museum of Alexandria over a millennium before. In this scientific environment Banu Musa were brought up and highly educated. They were said to have been skilled in geometry, ingenious devices, music, and astronomy. Muhammad, who was the most influential of the brothers, specialised in geometry and astronomy, and Ahmad excelled in all the sciences except in the construction of ingenious devices. Al-Hassan was a brilliant geometrician with a retentive memory and great powers of deduction.

Later, under the successors of the caliph al-Ma'mun, Banu Musa were wealthy, and came to be the most prominent and influential scientists in the history of this establishment. They were aware and conscious of the validity and value of the scientific culture of other civilisations. They generously devoted much of their wealth and energy to the quest for the works of ancient scholars, and sent missions to Byzantium to seek out such material. Muhammad is reported to have made a journey to Byzantium in person. Hill writes "The role of Banu Musa in fostering the work of translators and scientists can hardly be overestimated, but their own scientific achievements were far from negligible"[1].

The achievements of Banu Musa in science and engineering had flourished and brought forth the birth of the first book ever about the technology of ingenious devices, called *Kitab al-Hiyal*, The Book of Ingenious Devices. About this book and its scientific status al-Hassan affirms that:

> "Although Banu Musa wrote extensive and voluminous material on the mathematical sciences, the forms of the heavens, and planetary motion, nevertheless The Book of Ingenious Devices has remained the most prominent of their works. Wherever any description of, or reference to, Banu Musa's contribution was made, The Book of Ingenious Devices was sure to occupy the pride of place among all their works".[2]

The book of Banu Musa is the only example from that time while is concerned with pneumatic and hydraulic tradition in Islamic civilisation. We may gather from the works of other Muslim engineers that Banu Musa's work had no successors in the Islamic history, which is probably because it left little scope for development. Their work was focused mainly on exploring the area of pneumatics and aerostatics, as was the work of their predecessors, Philo and Hero. With very few exceptions, the only things that move in The Book of Ingenious Devices are fluids, and the components such as tipping-tanks and conical valves. Other devices incorporate simple mechanisms such as pulleys. The effects are obtained largely by using combinations of the basic hydraulic Motifs or components. Hill emphasised that:

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[1] Banu Musa (1) *The Book of Ingenious Devices.* Edited by Hill, D. (1979) p. 5.
[2] Banu Musa (2) *The Book of Ingenious Devices.* Edited by Al-Hassan, A. (1981) p. 11.

"Although Banu Musa took Greek models as their starting point, they went well beyond anything achieved by Hero or Philo. In particular, it is their preoccupation with automatic controls that distinguishes them not only from their Greek predecessors but also from their Islamic successors. Their use of self-operating valves, timing devices, delay systems and other concepts demonstrate great ingenuity. Of particular importance for future developments is their confident use of conical valves in a variety of different applications, and their incorporation of automatically operated cranks in several devices (Models 75, 78-83, 85, 87). Two of these Models (80 and 85) contain an action, which approximates to that of a crankshaft, anticipating by some five centuries the first known description of a crankshaft in Europe"[3].

Banu Musa's book The Book of Ingenious Devices enjoyed a great reputation for a very long time. It was highly esteemed, and numbers of copies of it were circulating as late as the 14^{th} century.

The only modern studies of major importance on The Book of Ingenious Devices are the papers published by two German scholars, Eilhard Wiedemann and Fritz Hauser in the early years of the present century[4]. They provide descriptions of the operation of the devices, together with modified copies of the original illustrations with Roman lettering. Later Hauser published a volume in which he covered all of the devices. This work is of considerable value and allows anyone with technical training and a working knowledge of German to obtain a good understanding of the operation of all the devices.

By all account, however, Hill and al-Hassan, throughout their works, came to an agreement that the efficiency of Wiedemann's and Hauser's work suffers from certain defects, for instance, the information they provide on source material is inadequate, since proper references, including the edition and date, are never given. For a wider public, Hauser's explanations of the principles - hydrostatic, aerostatics or

[3] Banu Musa (1) *The Book of Ingenious Devices.* Edited by Hill, D. (1979) pp. 23, 24.
[4] Hauser, Friedrichin (1922) *Uber das kitab al hijial -das Werk uber sinnreichen Anordnungen- der Benu Musa* Abhandlungen zur Geschichte der Naturwissenschaften und der Medizin. Heft I..

mechanical - that are embodied in the devices are seldom adequate for a layman. The most fundamental drawback, however, is that they were unable to distinguish between faults in the original work and faults made by the copyist, which is due to their ignorance of the existence of the TopKapi's manuscript, discovered later by Hill. Therefore they were handicapped and failed to arrive at a convincing judgement that Banu Musa were more precise than was suggested by the other manuscripts.

The recent substantial research which has been undertaken on The Book of Ingenious Devices is the English translation. In 1979 Donald Hill (an engineer and Orientalist) conducted a comprehensive and faithful work of translation of the entire book. By his unique work, Hill made this document well known in the Western world, and no longer just a legendary name.

In his work, Hill provided reproduction of the original drawings with Latin lettering. Annotations were given at the foot of each model wherever necessary. In addition, he included a biographical survey on Banu Musa accompanied with detailed reference to other similar known works. He ended his book with a glossary of Arabic terms and their synonyms in English.

After the appearance of Hill's pioneering work, in 1981 Ahmad al-Hassan issued the only Arabic edition of this book "*Kitab al-Hiyal*". He offered people with knowledge of Arabic a coherent work, which had never come to light before, and no other work so far has bettered this publication. In general, al-Hassan based his editing of <u>The Book of Ingenious Devices</u> upon Hill's work, to a certain extent he followed the annotations and the notes presented by Hill. By all accounts, however, very important analytical diagrams and explanations were given which must be credited to him. No doubt such a task was not easy to accomplish, even with the help of the outstanding work of Hill.

<u>The Book of Ingenious Devices</u> contains 100 models presented in both publications: the English translation by Hill and the Arabic edited version by al-Hassan. Most of the models deal with various principles of pneumatics, hydrostatics, and fine mechanics. About 87 models were describing different types of tricky

drinking vessels, jars, washing basins, and large drink dispensers. Four models were on constructing automatic lamps. Two other devices were described; the first was a bellows for removing foul air from wells, and the other a device for extracting objects from under water. There are seven models of fountains of alternating type and these are the main concerns of this present project. About these fountains in Banu Musa's work, in a review of Hill's book, Alex Keller writes:

> "Their study of fountains taught them [Banu Musa] how to produce different shapes of water jet: the 'lance', the 'shield', the 'lily-of-the-valley'. The motifs may be limited in number but they are ingeniously combined to give a variety of delaying and timing system, cut-off, and switch from one display to another"[5].

From an examination of these fountains Hill and al-Hassan, however, both tend to agree that some of the descriptive diagrams and text are far from clear. Therein the objective of this present work is based, through which an investigation on Hill's and al-Hassan's work will be undertaken, giving a representation of the fountain models in which each design will be clarified.

2. Method of investigation

Through the investigation I have carried out, I have come to this conclusion. The lack of clarity of the fountain's design in the work of Hill and al-Hassan can be attributed, in general, to a number of factors; Firstly, the poor and basic reproduction of the original drawings by both Hill and al-Hassan. This means that no convincing structure is given by which the mechanisms can be easily understood. Secondly, Hill added no modifications or explanation of the drawings, although al-Hassan did so; there are just some added corrections of missing parts of the drawing which had been described in the text. Thirdly, the operation of each model can not be understood from the drawing without reference to the descriptive text, and in many cases, not even then. Fourthly,

[5] Keller, Alex (1980) *Book Review (The Book of Ingenious Devices)* p.232.

in specific cases the illustration given does not correspond to the description in the text. Fifthly, this work on fountains has not been under investigation before this current thesis.

Since the materials concerned are relatively few, I have confined my investigation to the available published books of Hill and al-Hassan, as their works are, for the time being, the most coherent and complete publications available on Banu Musa's work. The work of Banu Musa, in fact, has not had the privilege of more studies after the published works of Hill and al-Hassan, which I have come to know from several contacts with al-Hassan and the intensive literature review that I have undertaken. Therefore the reference material seems quite limited. This is, in fact, the unpleasant case with all fields of Islamic science and technology. Fortunately, a section of an Arabic manuscript I have discovered in John Rylands University library of Manchester (unknown date), of which Hill and al-Hassan were not aware describes some of Banu Musa's fountains, and has been used as a secondary reference in my work.

Allowing that the current investigation is not intended to discuss, specifically, the materials and measurements of each device and its component; no detail will be given of these unless any of these components have been examined as part of a specific model and its testing. Banu Musa, however, had no concern with satisfactory dimensions and were careless in providing exact proportion of the devices in relation to their parts. They hardly mentioned measurement; like finger-size and like brass for materials; this applied to all devices they included in their book. Banu Musa were mainly concerned with presenting what they had made of such ingenious devices regardless of any thing else. However, measurements and materials in use at their time were probably very similar to those used by al-Jazari, four centuries later. As far as the fountain is concerned we may suppose that the materials used were varied in accordance to design requirements; size and site, etc. For all these fountains, in order to site the housing of the device, machinery-box, and obtain an adequate static head of the fountain above the pool; it would have been necessary to work out the land surveying techniques.

Through the development and testing of some components of actual models derived from the information given, I have been able to present a clear understanding of the principles involved and their specific interpretation within each application. The following analytical explanations are intended to investigate and represent a clarified image of each model. The method followed here consists of three stages:

1. Discussion of the work of Hill and al-Hassan accompanied with commentary notes, concentrating on their interpretations of the mechanical concepts involved. However, for better understanding of my comments, the reader may refer to the drawing I have reinterpreted and reconstructed to understand the nature of mechanism involved, and to make himself/herself familiar with the terminology used. In doing so I have avoided repetition of unnecessary description since all will be very clearly presented in my description of the construction and the operation of the fountain.

2. Re-presentation of each model in terms of the construction and the operation of each device, as well as the applications of its components, supported by reconstructed and detailed illustrations. This will make the fountain more understandable, rather than going through the original description presented in Hill's and al-Hassan's work.

3. Experimental work that I have undertaken to examine the fountain-head will be presented separately at the end of this section. There will be also a video recording of these experiments in order to give the reader a clear visual presentation of this unique fountain-head.

3. FOUNTAIN NO. (1)

3.1. About the fountain.

This fountain was constructed with a single fountain-head. No mechanical device was applied. It is basically designed to produce the shape of a shield or lily-of-the-valley, in constant emission. The two different displays of water are determined by modifying its fountainhead. The key concept of the fountain's operation is the high static pressure of water. This requires a proper sizing of the feeding-tank, which is positioned at some distance from the fountain, and above its altitude. Drainage is another essential element that is to maintain the perpetuity of the fountain. For a stream or a pipe of water was diverted from a nearby running water source (rivers, springs, etc) that set to feed the fountain constantly; the water then is recharged into the water source after being used to operate the fountain. As an architectural setting, the fountain-body always centred in a pool or a basin, and was partially submerged. Thus it was set to serve ritual and aesthetic purposes within both religious and secular buildings.

3.2. Discussion of Hill's and al-Hassan's works.

- Hill gave no satisfactory design analysis on the unclear parts, he mentioned, in Banu Musa Drawing (fig. 17), which is about the peculiar fountain-head; even the reproduction of the original drawing by Hill bears the same ambiguity (fig. 18). Al-Hassan, on the other hand, followed Hill in his notes that provide no proper justification on the relation between the conic shape of the fountain-head and the swirling motion of water he presumed (fig. 19). This particular fountain-head is examined later in this chapter, in which Hill's assumption is compared with the experiments I have undertaken.

- By looking at the drawing (fig. 18) it obviously, shows a funnel-like shape aze rather than a cone, despite the fact that Banu Musa mentioned a cone-like shape in the text. From a practical point of view, the funnel-neck that Hill presumed would have constrained the velocity of water, as well as the impartiality of a swirling motion created by the inclined jets. I have clarified this in my experimental work (at the end of this section), which sustains my judgement on Hill's interpretation. The enigmatic point in the drawing can be attributed to the single presentation by Banu Musa of the two fountain-heads setting, which are to produce the shape of a shield or lily-of-the-valley. But, by looking at the other fountain models, which were intended to produce the same shape of the lily-of-the-valley, we find there was no single cone that had an extension on its top. What we find is a jar- like-orifice, and each cone had a curved edge instead of the sharp edge of this model.

- To clarify the setting of each fountain-head I have reinterpreted the construction of these two fountains. Figure 20 shows a separate reconstruction of the first fountain with a fountain-head that emits the shape a shield. The vertical tube erected on the centre of a partitioning plate, around the top-end of this fountain-head an adjustable round plate is inserted. By adjusting the gap created between the round plate and the orifice of the sphere, the diameter and the thickness of the shield is determined. The drawing in Figure 21 shows the second fountain the fountain-head of which produces a lily-of-the-valley. The construction of this fountain-head is described in experimental work provided.

- A fragment of treatise (fig. 22) I have discovered, mentioned earlier, shows the arrangement of the small pipes, which were erected on the partitioning plate, and differs from that shown in the edited work of Hill and al-Hassan. This ingenious arrangement of these pipe is the key concept to producing the shape of a lily-of-the-valley, which puzzeled Hill and al-Hassan. the drawing shows a circle of small inclined pipes is set somehow close to the cone's wall, each of which is directed towards the fountainhead at the same angle.

3.3. Construction of the fountain.

- Supply tank:

  Above the altitude of the fountain-head an appropriate tank is located from which Delivery pipe (d) is led down and is brought up in the pool to deposit the water into the fountain's body.

- Fountain's body:

  A spherical metal body (b) with an inlet at its bottom and an opening on the top forms the fountain (fig. 20, 21). Plate (pp) partitions the fountain's body, on which a circle of small inclined pipes is erected (j).

- Fountain-head:

  (1) In the case of producing the shield an upside-down small cone (c) with narrow horizontal bent-edge is fitted to the top of the body shaping the fountain-head. In the centre of this partitioning plate, a vertical tube (v) is erected. At the other end of this tube, above the fountain-head, a round plate is inserted, leaving a small gap (g), from which water outflows to create the shape of a shield (fig. 20). (2) On the other setting that producing the lily-of-the-valley, a cone with a jar-like-orifice opening is erected on the partitioning plate instead (fig. 21) with a slightly bent orifice over the opening of the sphere.

3.4. How the fountains operates.

Water flows into the tank, from which pipe (d) deposits water into the lower part of the fountain's body through the inlet. Then water surges into the upper part of the fountain through the inclined jets (j). In the case of the shield setting, water flows from the narrow gap at the fountain-head creating the shape of a shield (fig. 20). When on the other setting, water discharges from the cone orifice fountain-head, to produce the shape of a lily-of-the-valley (fig. 21).

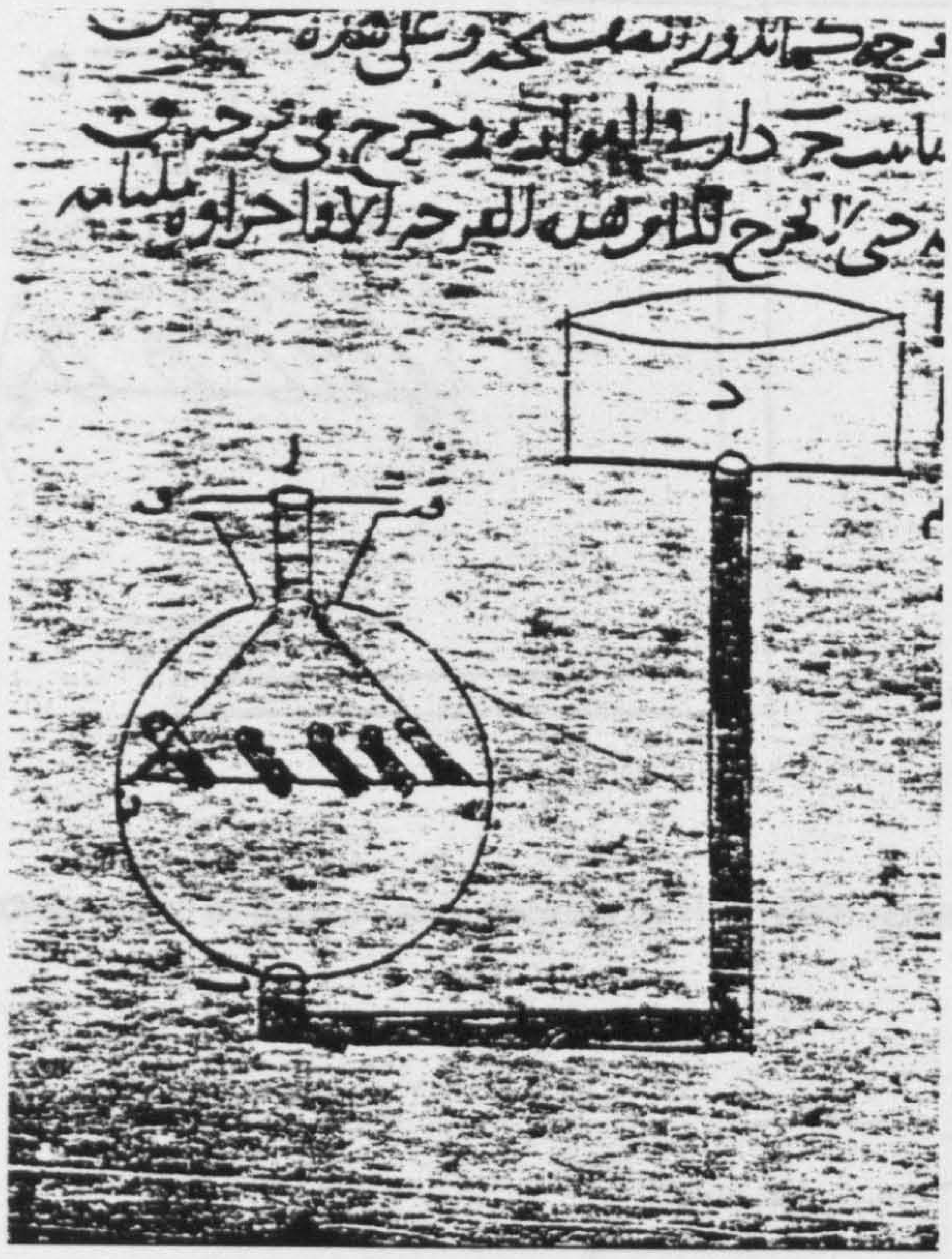

Figure (17)

The original drawing of Banu Musa as it is presented in Hill's book. This drawing shows a single presentation of the two shapes of emission (Shield, Lily-of-the-valley) which by no means can be understood.

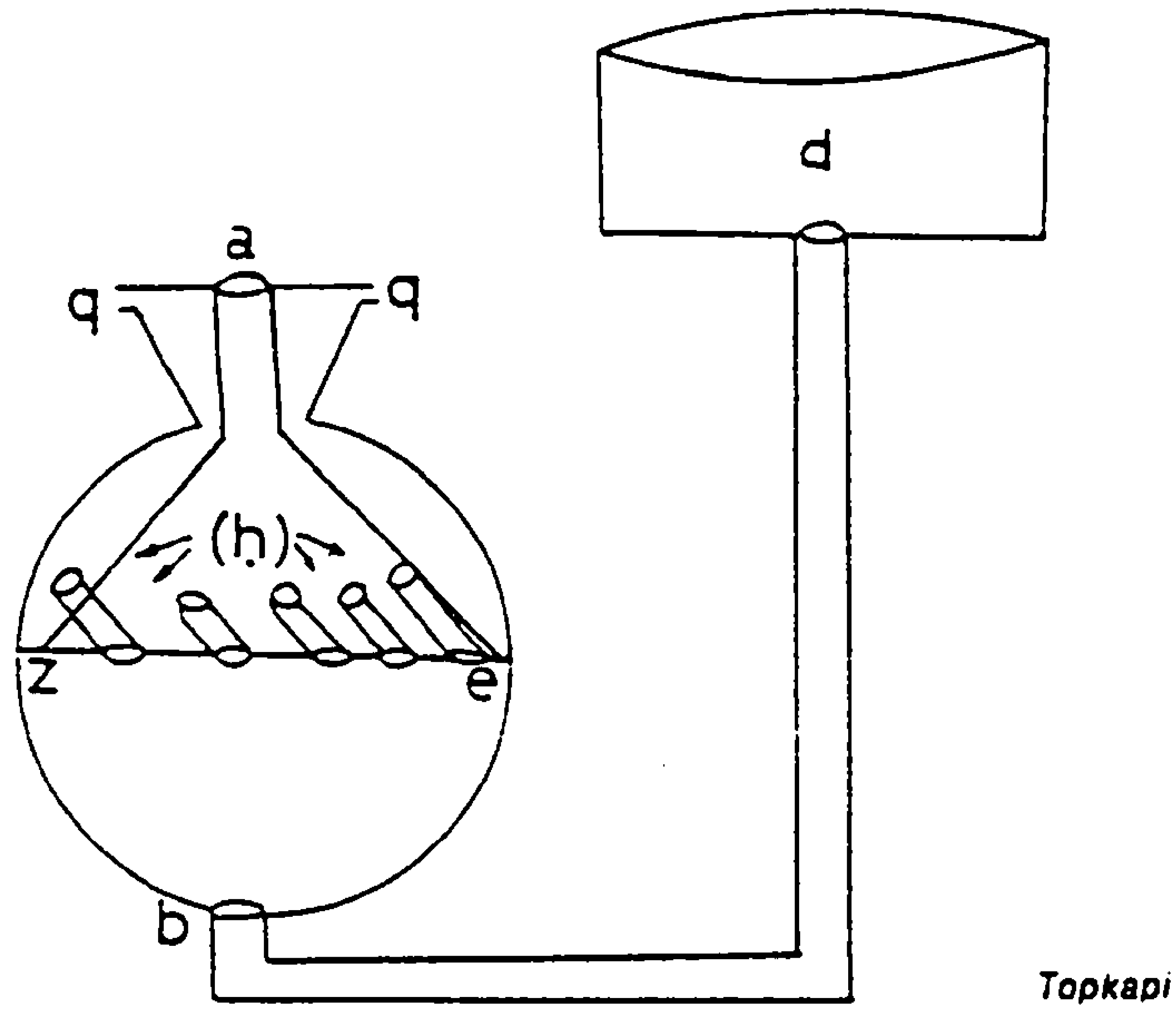

Figure (18). The reconstruction of Banu Musa's drawing by Hill, which remains obscure.

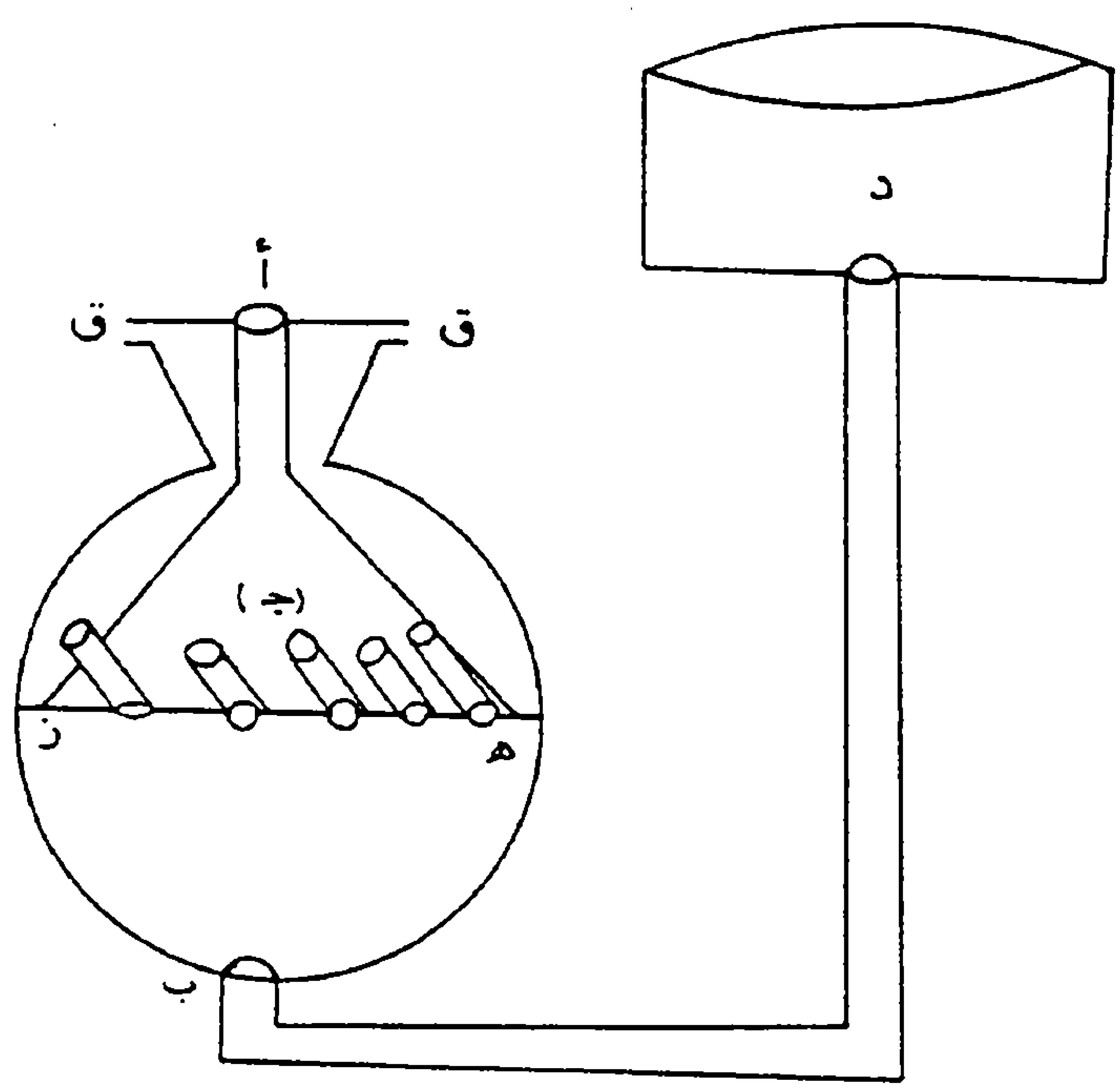

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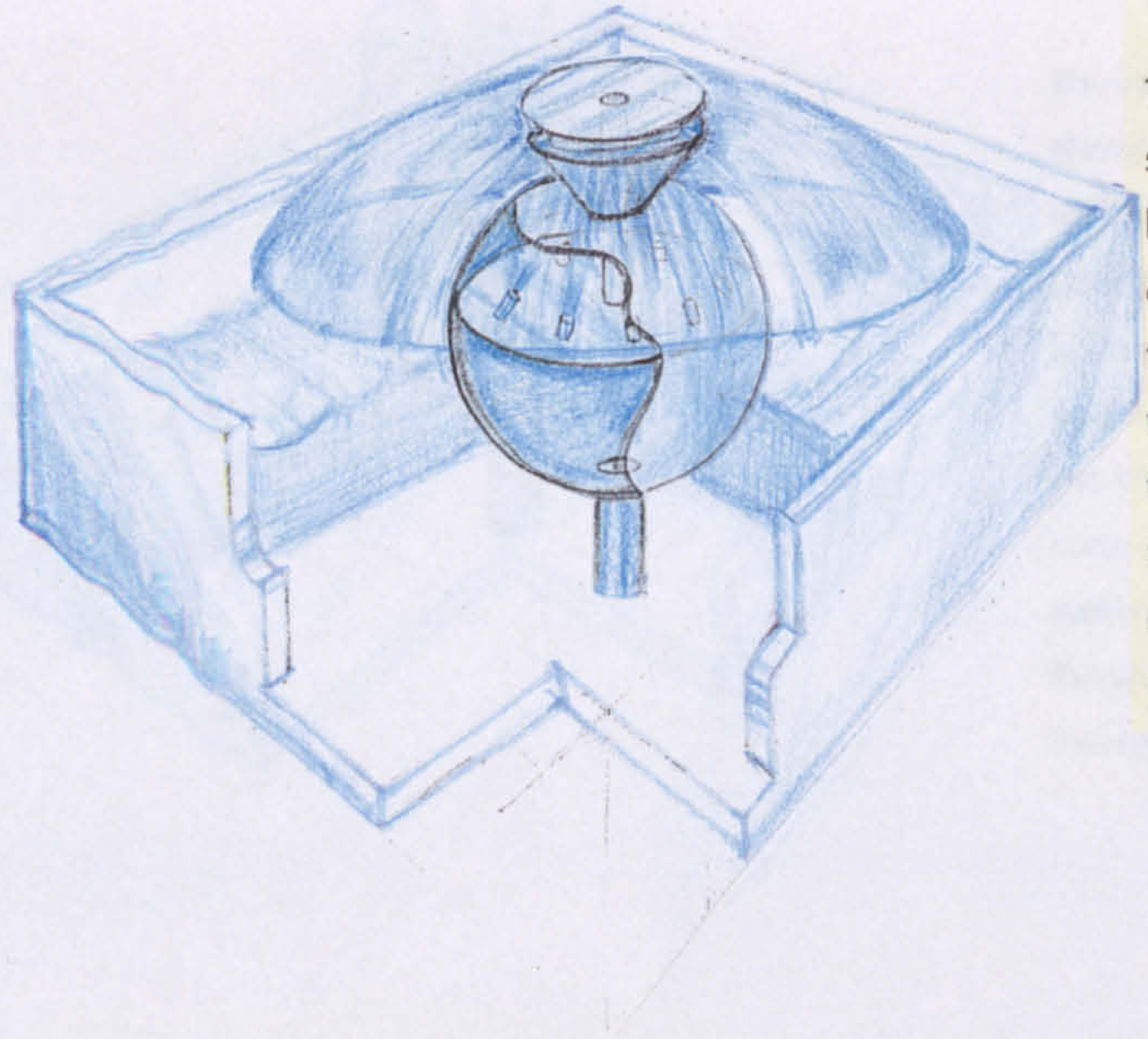
Figure (19). The reconstruction of Banu Musa's drawing by al-Hassan, which is still unclear as is in Hill's.



Fountain-head

The inclined jets shown inside the body of the fountain are set to increase the water pressure that passes through the gap at the fountain-head to creates the shape of a shield.

Supply-channel & Feeding-tank

The water that diverted from a near-by running water source is delivered through the supply-channel to be deposited into the feeding-tank.

Drain

Through this drain the water that is being used to operate the fountain is discharged into a nearby running water source, from which the water is initially diverted to supply the tank. So this process maintains the perpetuity of the fountain

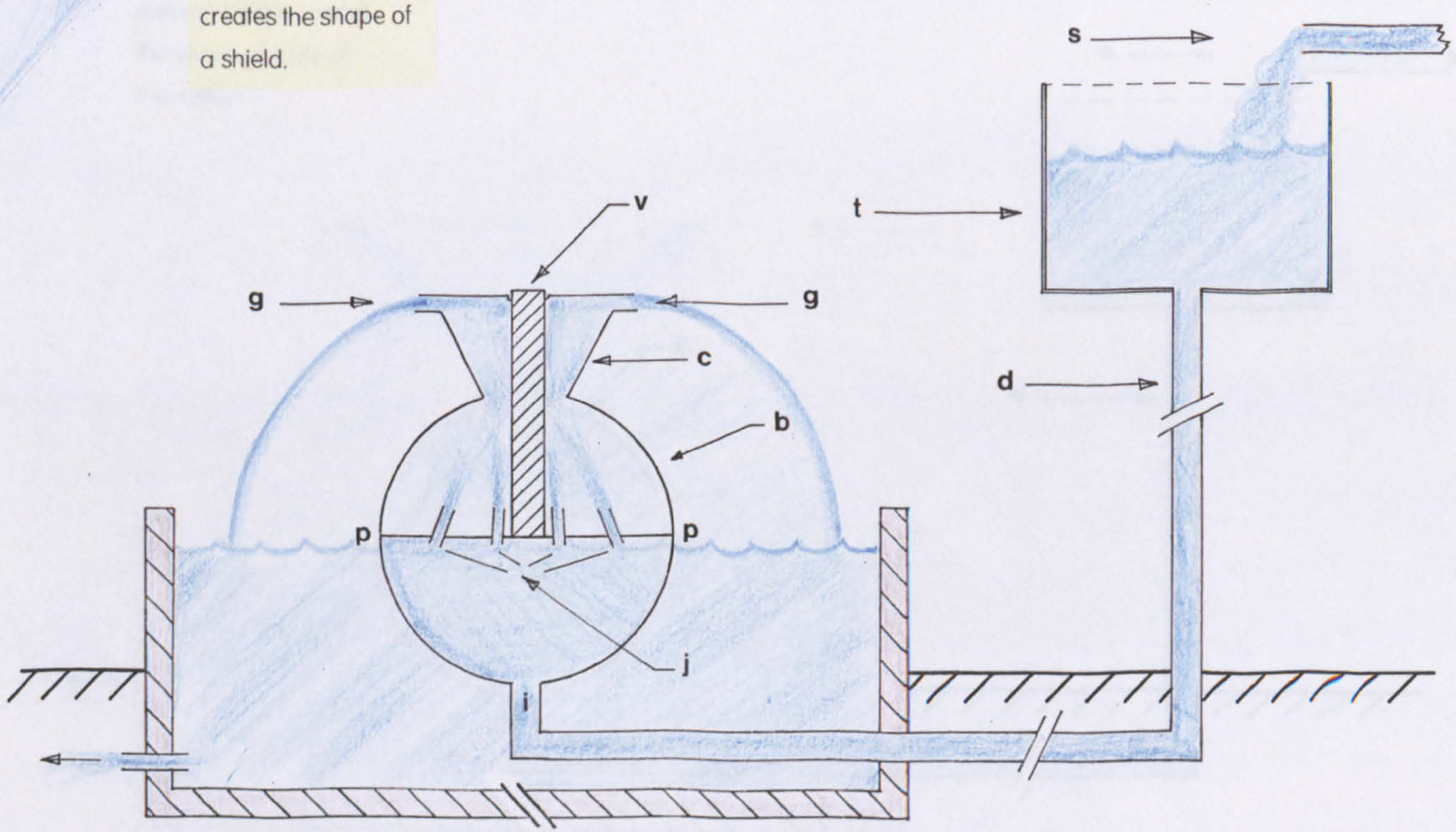
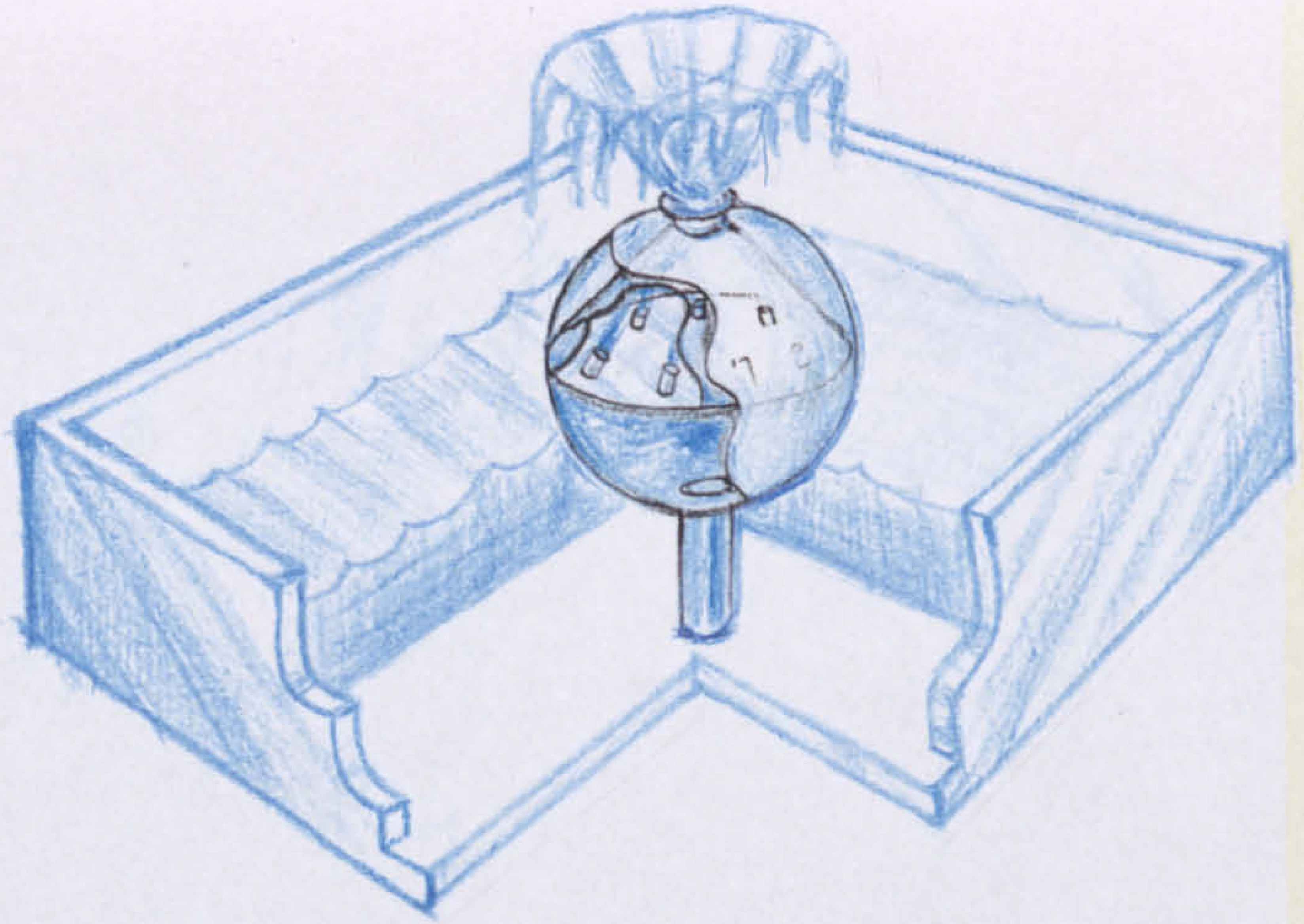


Figure 20: Reconstruction of the fountain's drawing in which the fountain-head designed to produce the shape of shield.

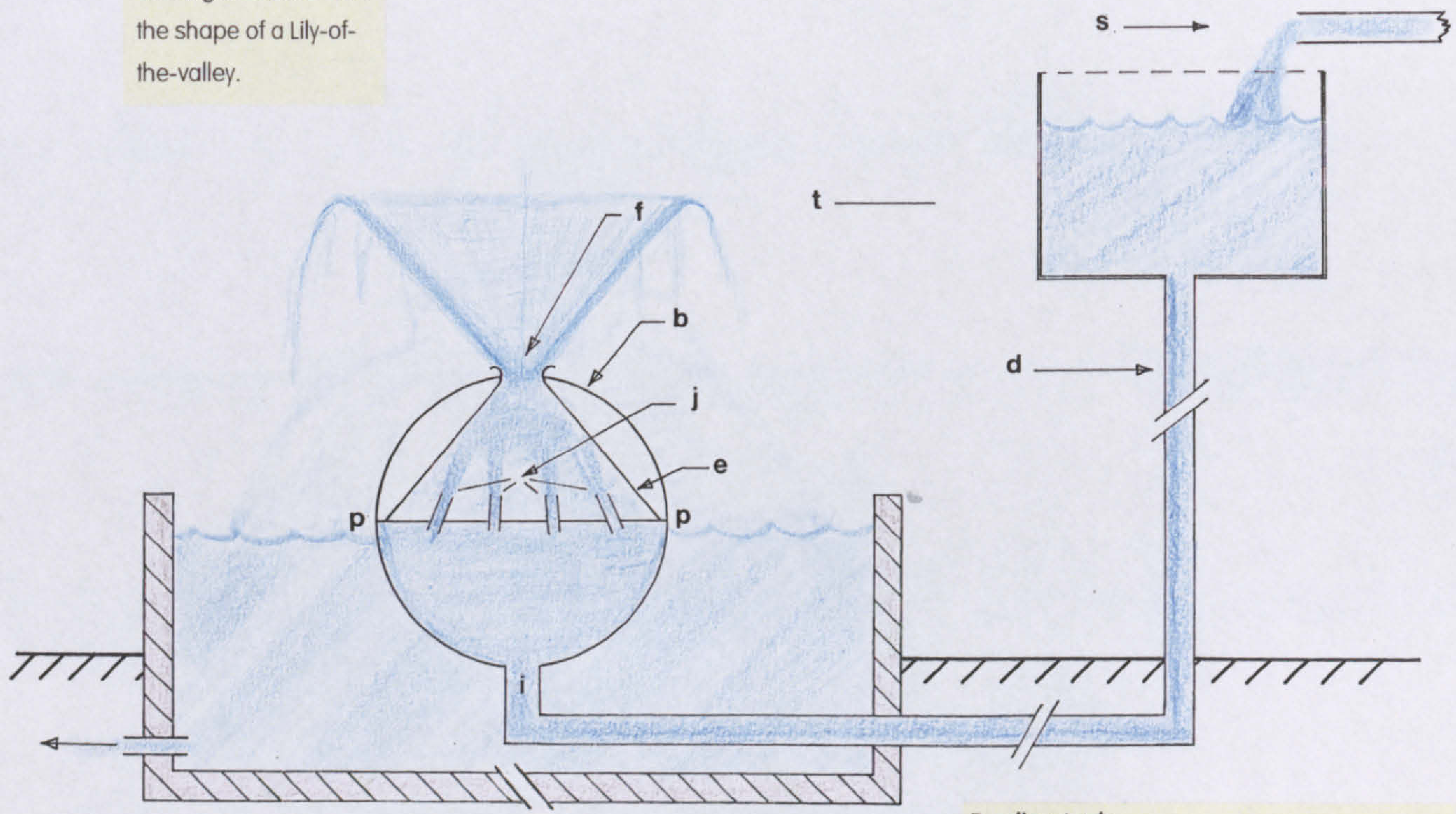


Fountain-head

The inclined jets shown inside the body of the fountain are set close to the cone wall. So the water that outflows through these jets hits the wall of the cone creating a swirling motion to emit the shape of a Lily-of-the-valley.

Supply-channel

This is a constant source of water that is diverted from a near-by stream or river .



Drain

As in the previous model the water passes through the draining pipe to be discharged into a nearby running water source. The size of this drain is worked carefully with the volume of water deposited into the fountain and the size of the pool.

Feeding-tank

This tank is erected and hidden above the fountain altitude in accordance to land surveying and the fountain-head size.

Figure 21: Reconstruction of the fountain's drawing in which the fountain-head designed to produce the shape of Lily-of-the-valley.

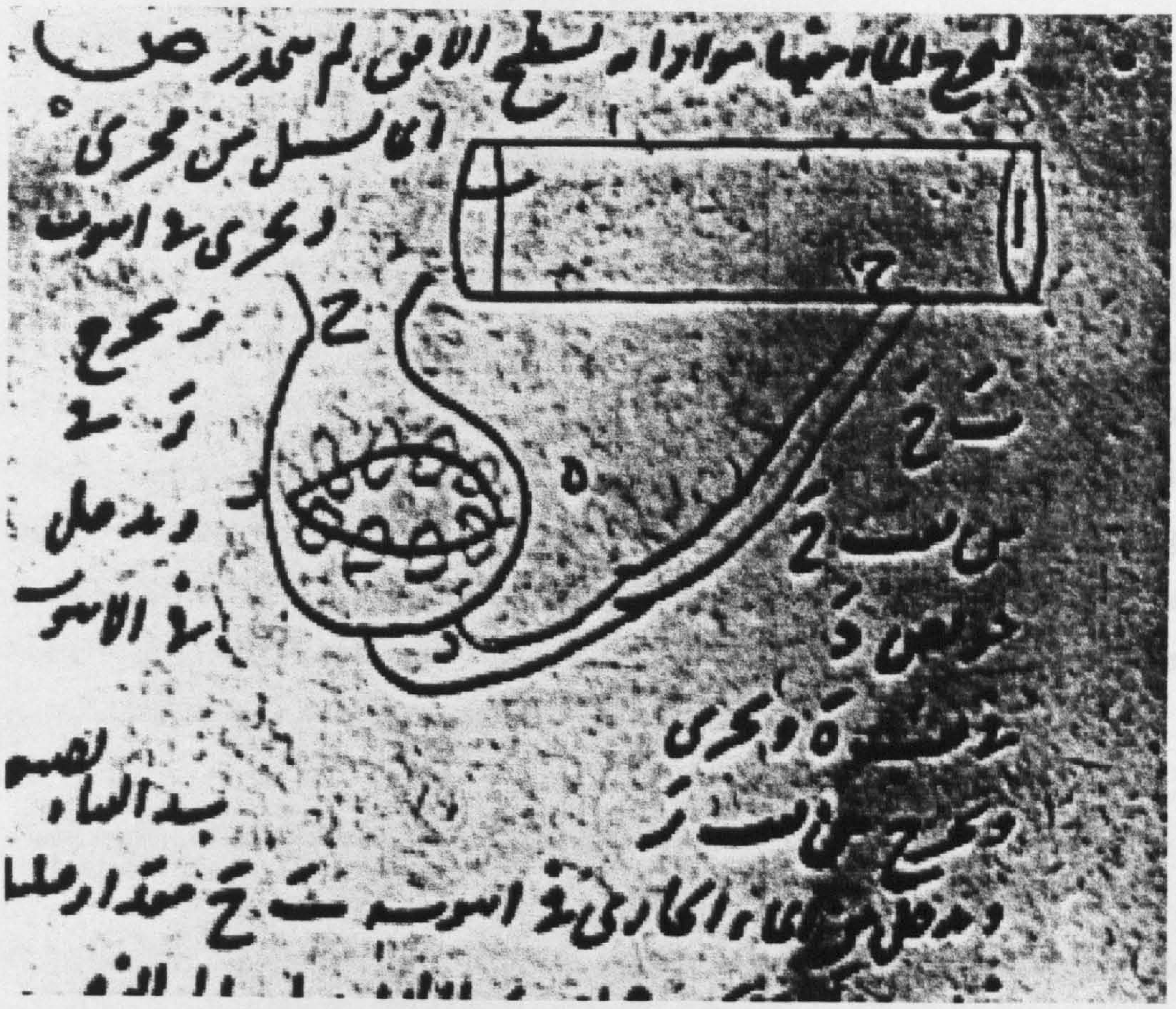


Figure (22). A drawing of the fountain from The John Rylands Library (Arabic Ms, 351 [419] section B). It shows a circle of jets erected on the partitioning plate in the fountain body.

4. FOUNTAIN NO. (2).

4.1. About the fountain.

This fountain is of an alternating type, which produces the shape of a shield for a period of time and changes to a lance for the same period in a perpetual manner. The alternation is based on an imbalance-tank concept that operates by water-powered mechanical movements. The device housing is to be erected at some distance from the fountain and above the altitude of its head. This setting, as in the other models, was meant to provide a high static pressure of water, which is essential to maintain the fountain fluidity. The key to a successful operation of the device depends upon the proper sizing and positioning of each component in relation to the other, which requires substantial work on adjustments and setting-up procedures. More importantly, weight (full and empty) of the mechanical components that the alternation mechanism was linked to, has to have been taken into consideration; this will be clearly explained and illustrated.

4.2. Discussion of Hill's and al-Hassan's works.

- Figure 23 shows a single chain attached to the imbalance-tanks. Figures 24 and 25 by Hill and al-Hassan reproduced this incomplete drawing of Banu Musa. However, a similar device with a double chain is shown in model (91). Therefore, the two small imbalance-tanks (this can be seen clearly in figure 26) attached to the balance-pipe are to be suspended with a chain from either side. Practically, the chains allow a flexible movement of the two joined tanks as the first one is filled through the bleeder-pipe, where it results in tilting the balance-pipe. Then water is evacuated into the adjacent tank through a middle hole.

- Another important mechanism of the imbalance-tanks, which was not mentioned by Hill and al-Hassan, is the acute angle of the bottom of the two suspended-tanks. It was set to serve two important purposes. First, to have increase the evacuation of water as it is discharged from tank (y) into the adjoining tank (x). Second, to have allowed a complete discharge of water from tank (x) through its bleeder-pipe (h2) as the angle of its bottom returned to horizontal (figure 26).

- Hill pointed out that the small-penetrated upstanding pipe in the supply channel as may have served the purpose of insuring that sand or other physical impurities did not enter the receiving tank; and al-Hassan agreed with him. More precisely, such unwelcome impurities would have blocked the two bleeder-pipes (hl, h2) and have paralysed the movement of the device; that is why Banu Musa did introduce this pipe which cannot be found in other models which have no bleeder-pipe. Another function of this pipe probably was to have maintained a maximum steady flow of water into the receiving tank. This, to a certain extent, is important for measuring the counter-balance needed against the exerted force on the receiver caused by the fall of water (see fig. 26).

- In his reproduced drawing (figure 23) Hill also showed a modified receiver-tank with a rectangular shape in section. But this receiver as shown in Banu Musa's drawing was of a trapezoid shape.

We may, therefore, infer from the detailed drawing I have provided (figure 26) that the design concept of the receiver-tank was meant to serve two practical aspects. First, to ensure that the receiver maintains the maximum proximity to the supply-channel without hitting its upstanding pipe as the balance-pipe swings, allowing water to flow into the feeding-tank beneath. Second, to diminish the tilting span of the balance-pipe, on which the receiver is attached, which accord to the proper sizing and positioning of the imbalance-tanks.

4.3. Construction of the device.

- Feeding-tanks:

  Two adjoining tanks (t1, t2) are connected by a fulcrum (f) which is erected with a horizontal pivot (e) connected to the balance-arm. The height of the fulcrum is to be measured in accordance with the length of the balance-pipe, and its tilting span. Wide pipe (m) links the bottom of tank (t2) with the fountain inlet. A thinner pipe (n) is inserted through pipe (m), where one end terminates at the fountain-head, and the other end penetrates the partitioning wall between the feeding-tanks into tank (t1).
- Balance-pipe:

  Pipe (d) is pivoted on the fulcrum (f), on one end of which a small tank (receiver) is fixed (c). The other end of the pipe is bent, from which water is delivered into the feeding tank below. A thin pipe (h1) is branched from the balance-pipe on the side of the delivery pipe to serve the purpose of a bleeder. Two small-suspended tanks (y, x) are attached to the balance-pipe by chains from either side. Tank (y) is positioned right below bleeder (h1) into which the bleeder tips.

4.4. Construction of the fountain.

- Body of the fountain.

  A spherical metal body (b) forms the fountain. A streamlined urn-like opening is fitted to the top of the body to shape the lower part of the fountain-head. Plate (pp) partitions the fountain's body, on which a circle of small-inclined pipes (j) is erected.
- Fountain-head:

  On the end of pipe (n) as it terminates above the fountainhead, a round plate formed in a shallow conical shape is inserted, leaving a small gap. By adjusting it, the size and the thickness of the shield are determined (fig. 26).

4.5. How fountain operates.

Water flows from supply-channel (s) into receiver-tank (c), running through the balance-pipe (d) from which water descends into feeding-tank (t1). At the same time, the bleeder pipe (h1) tips into the small suspended-tank (y). From tank (t1) water passes through the narrow pipe (n) terminating at the fountain-head to produce the shape of a lance. The jet continues shooting up until tank (y) is filled and results in imbalance, which causes the balance-pipe (d) to tilt towards the imbalance-tanks. Then water evacuates from tank (y) into adjacent tank (x) through hole (z). As the receiver-tank (c) on the other end of the balance-arm rises up away from the supply-channel (s), water starts to flow downwards into next feeding-tank (t2). Pipe (m) delivers water from tank (t2) down to the fountain's body. Then water forces its way through the numerous inclined-pipes (j), which are erected on the dividing plate (pp). Then a shield shape is created as water passes through the gap (g). This shape continues for the same period of time as for the lance. The interval obviously, coincides with the evacuation of water from the suspended tank (x) through the bleeder (h2). As water is emptied out from tank (x) the balance-arm tilts back to its horizontal position, and the motion is repeated perpetually, since water continues to flow.

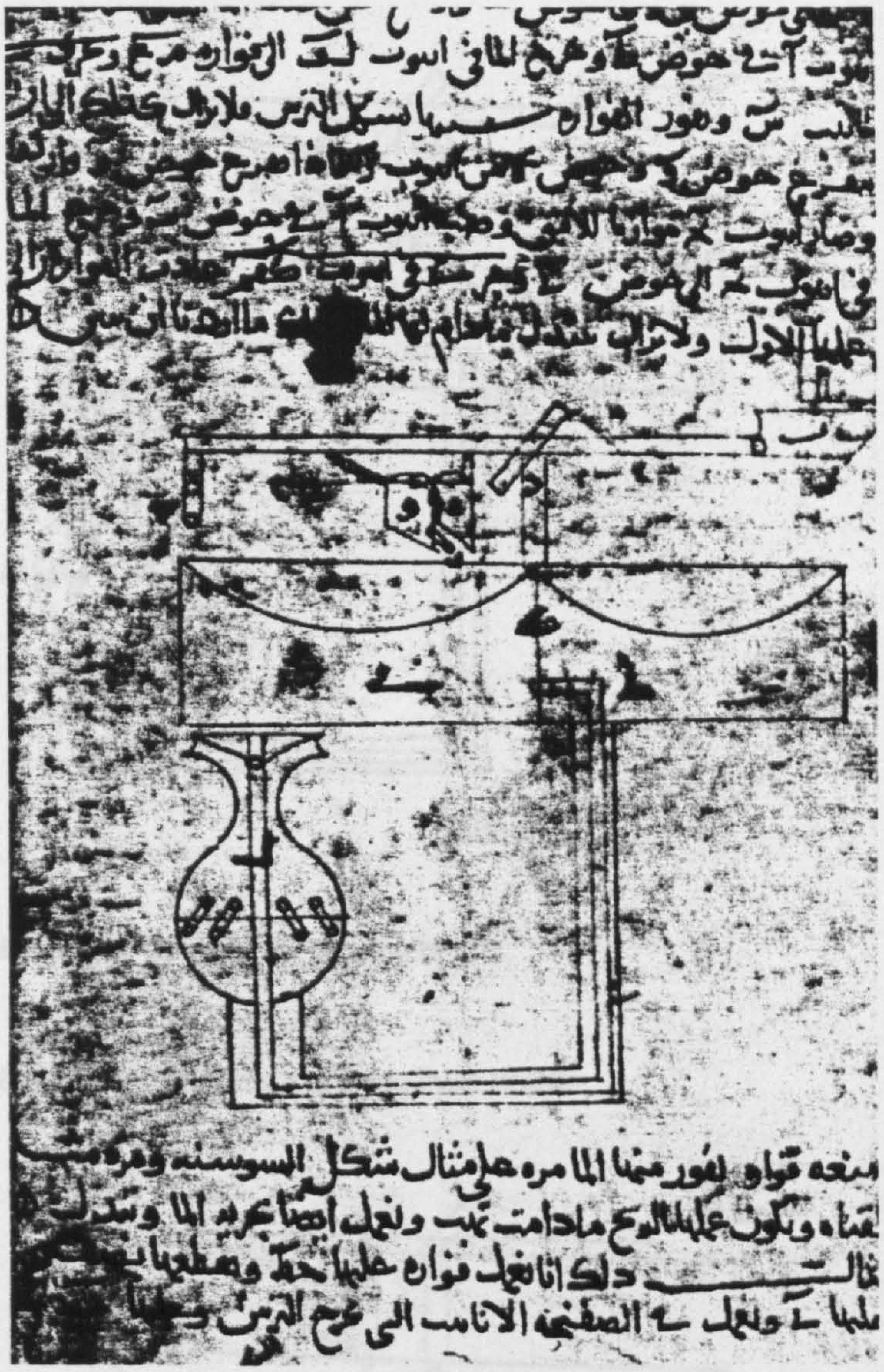
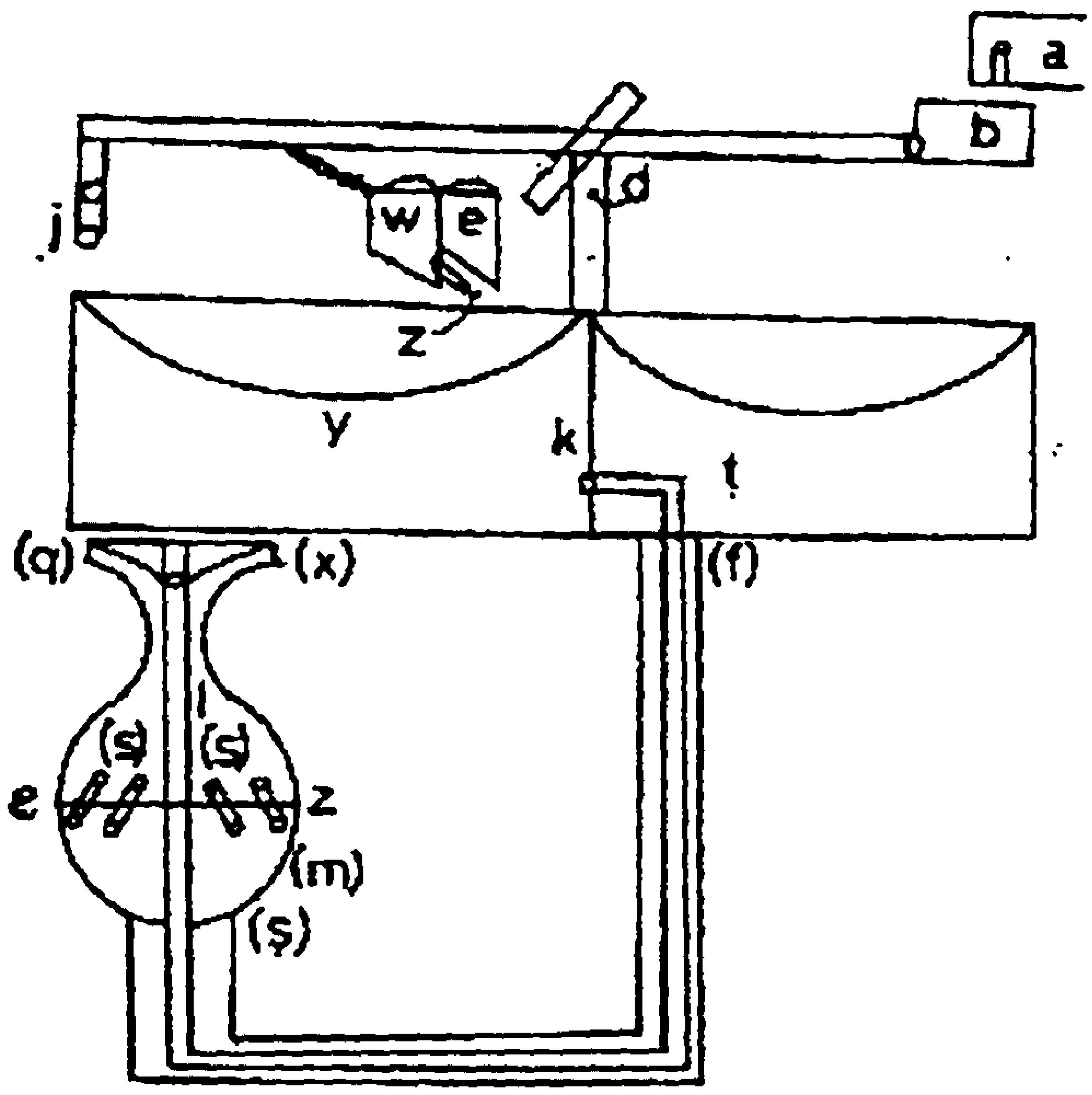


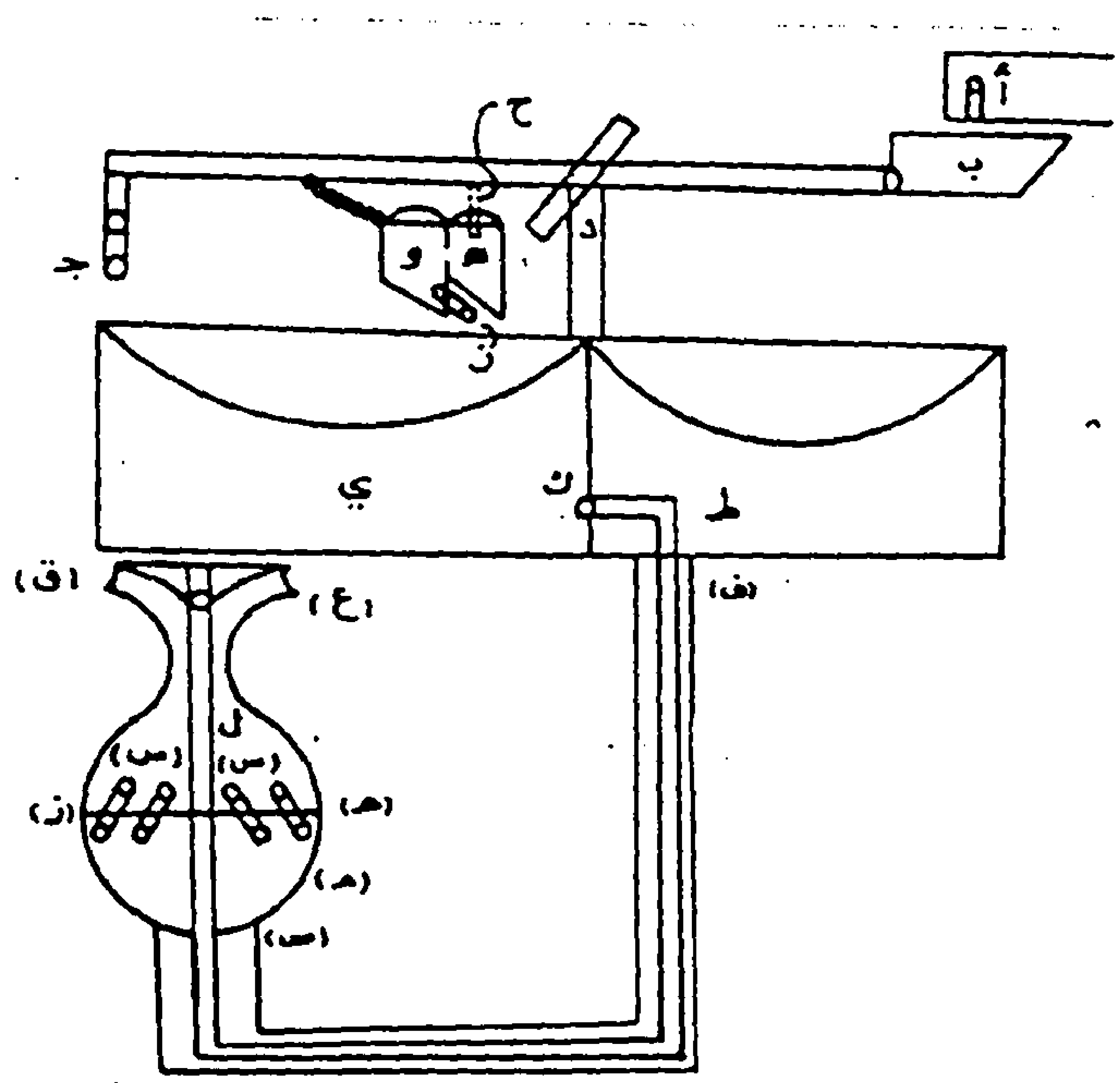
Figure (23). The original drawing of Banu Musa as it is presented in Hill's book.



Vatican

Figure (24). Reconstruction of Banu Musa's drawing by Hill.

Figure (25). Reconstruction of Banu Musa's drawing by al-Hassan.



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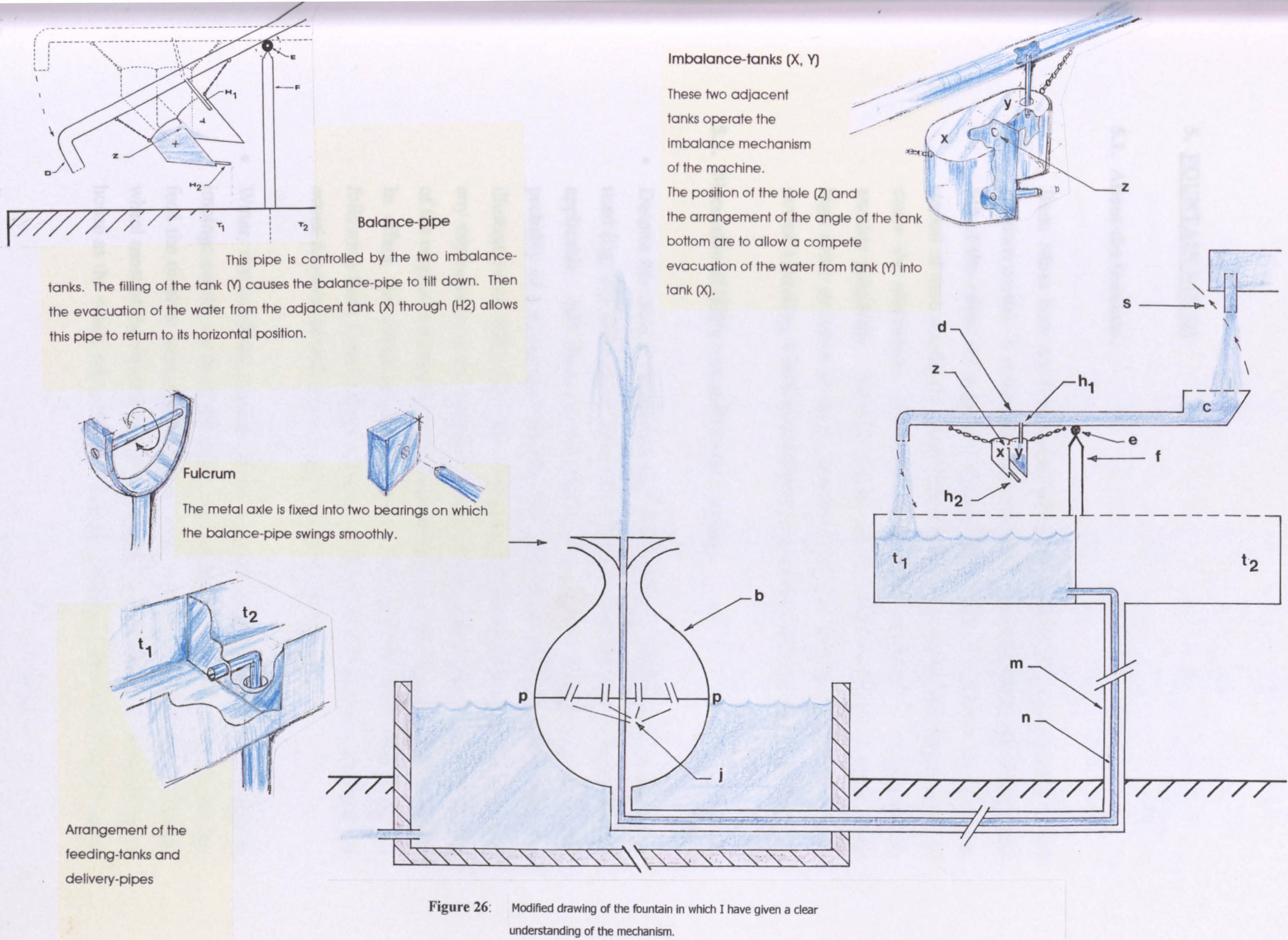


Figure 26: Modified drawing of the fountain in which I have given a clear understanding of the mechanism.

5. <u>FOUNTAIN NO. (3)</u>

5.1. About the fountain.

Banu Musa here are introducing different mechanical concepts than in the previous model. It is also of alternating type, which produces the shape of the lily-of-the-valley for a period of time and changes to a lance for the same period of time constantly. The idea is based on a water-wheel mechanism to cause the alternation. However, Banu Musa mentioned a wind-wheel as another possibility. The key concept of the operation of the fountain is the high static pressure of water obtained from the feeding-tank located in the device's housing, which is considered as a primary setting of all fountains.

5.2. Discussion of Hill's and al-Hassan's works.

- Despite the illusive description and illustration by Banu Musa of the wheel used (fig. 27), the concept of a water-wheel is really the only type that can be applicable. Hill discussed this matter in his notes determining that it was probably of a horizontal type (fig. 28). Al-Hassan added no further notes or illustration on Hill's (fig. 29). Furthermore neither Hill nor al-Hassan gave any explanation on the practical concept of the wheel. And their reproduction of the original drawing made no better ideograms than the ones of Banu Musa. In effect, the drawings remain rather crude and far from clear. In the following lines I will discuss a number of points which should elucidate the actual function of such a wheel and clarify its operation.

- Water, that outflows through the jet from the supply-channel, is intended to impinge on the vanes of the wheel and rotate its axle, and at the same time, feed the receiver tank attached to the axle. In the case of a horizontal vaned wheel most of the water would have splashed against the walls of the device's house as the wheel set in motion. Unless, possibly, some sort of spiral wheel with top and bottom covers was used, or other similar wheel. This would have decreased the loss of water, which appeared to be driven water through holes at the outside ends of each slot straight into the tank below. See the drawing I have provided in figure 30.

- Another possible way of preventing water loss is by enclosing the vaned wheel with walls, which would insure a maximum use of water (see fig. 30). A sub-boxing of the wheel is also another alternative.

- The drawing of Banu Musa (fig. 27) shows an unnecessary span between the wheel and the receiver tank, which is reoccurred in the reproduction by Hill and al-Hassan. Clearly in such arrangement which requires more efficient use of water, the closer the wheel is to the tank the less water is lost.

5.3. Construction of the device and the fountain.

- Feeding-tanks:

  Two adjoining tanks (t1, t2) are erected from which two pipes descend and brought up in the middle of the pool. To tank (t2) the wide pipe (m) is linked from one end while the other end of the pipe is fitted to the lower section of the fountain. The narrow pipe (n) is led from tank (t1) penetrating the wall between the two tanks and then is passed through the wide pipe (m) to terminate near the fountain-head.
- Vaned-wheel and the receiver-tank:

  Axle (f) is set perpendicularly with the centre of the partitioning plate of the tanks, which rotates in two bearings (e1, e2). This axle is passed through the bottom of cylindrical tank (t3) and is fixed to its lower part. Hole (z) is made somewhere at bottom of the wall of the cylindrical tank (receiver). To the upper part of the axle, an enclosed vaned wheel is attached near to supply-tank (t3).

- Body of the fountain. A spherical metal body (b) forms the fountain. A streamlined opening with a jar- like-orifice shaping ups the fountain-head. Plate (pp) partitions the fountain's body, on which, a circle of small inclined-pipes is erected (fig. 30).

5.4. How the fountain operates.

Water flows from the supply channel hitting the vanes of wheel (w). This drives the wheel, which in turn rotates the axle (f). The receiver-tank (t3), through which the axle (f) penetrates, receives the falling water that has been used to rotate the wheel (w). From hole (z) in the bottom of tank (t3), water discharges into the feeding-tank (t1) for a period of time that coincides with a 180-degree rotation of the tank (t3). Pipe (n) delivers water down from tank (t1) up to the fountain-head to produce the shape of a lance. As a half circle rotation of tank (t3) is completed, hole (z) comes into position above the tank (t2) and discharges water into it. From this tank, pipe (m) deposits water into the lower part of the fountain's body. Under high static pressure, water outflows from numerous inclined-pipes (j) upward to the fountain-head to produce the shape of the lily-of-the-valley. Interval timing coincides with the half-complete rotation (180-degree) of hole (z) to change from one shape to another. In technical terms, the bigger the diameter of the receiver-tank the longer the rotation of hole (z) lasts and consequently, a longer interval is set.

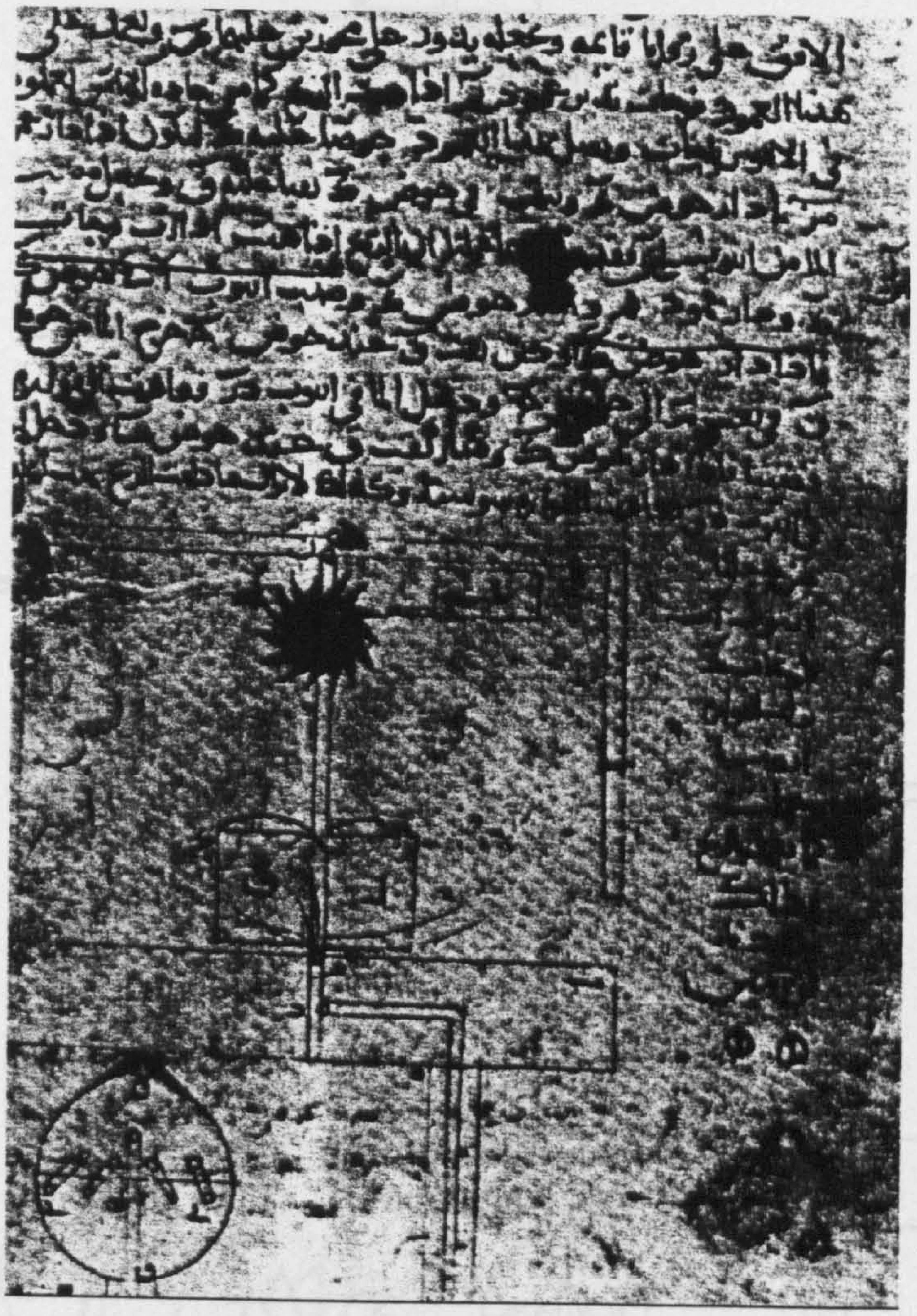


Figure (27) Banu Musa drawing that is shown in Hill's book.

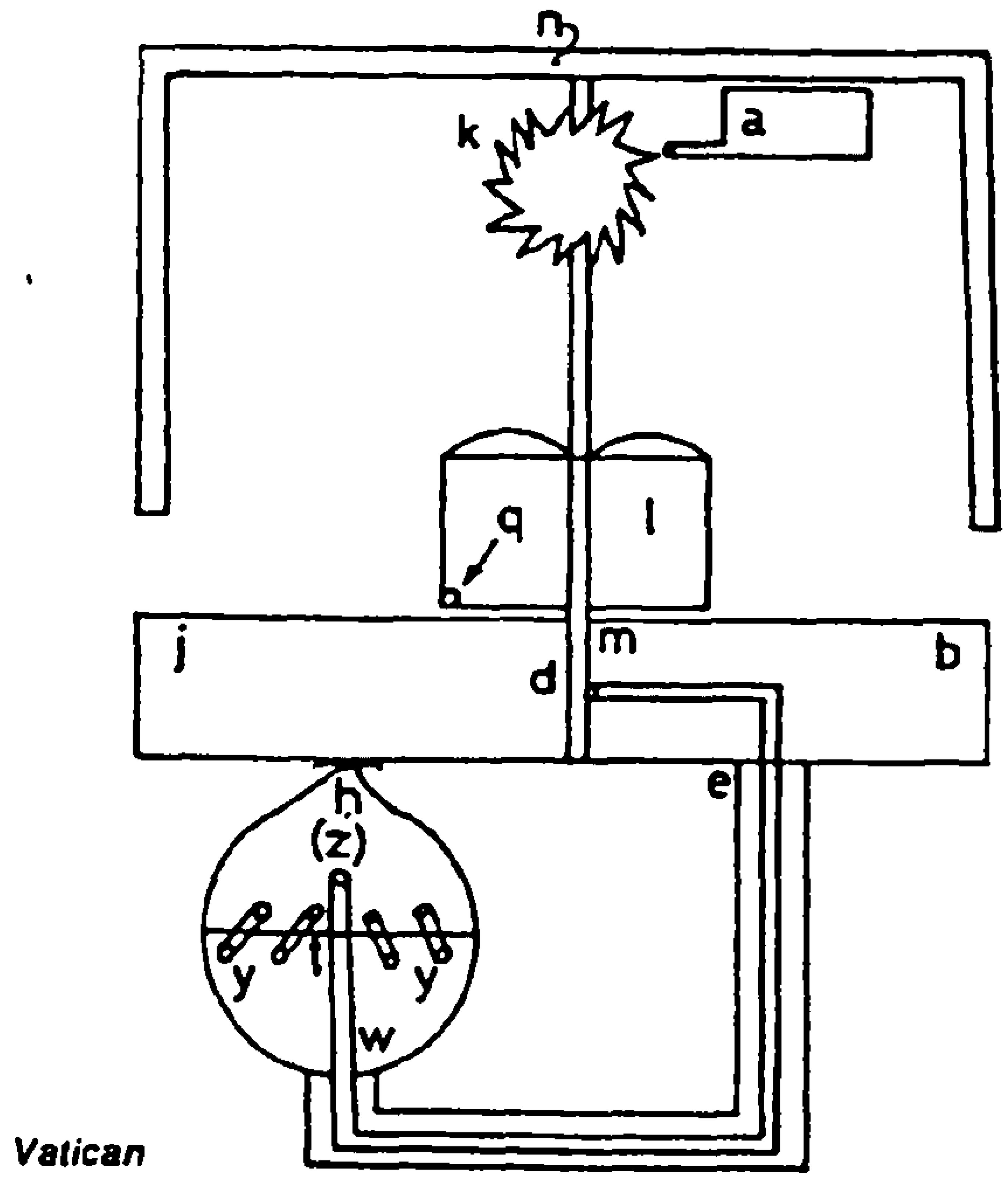


Figure (28). The reconstruction of Banu Musa drawing by Hill.

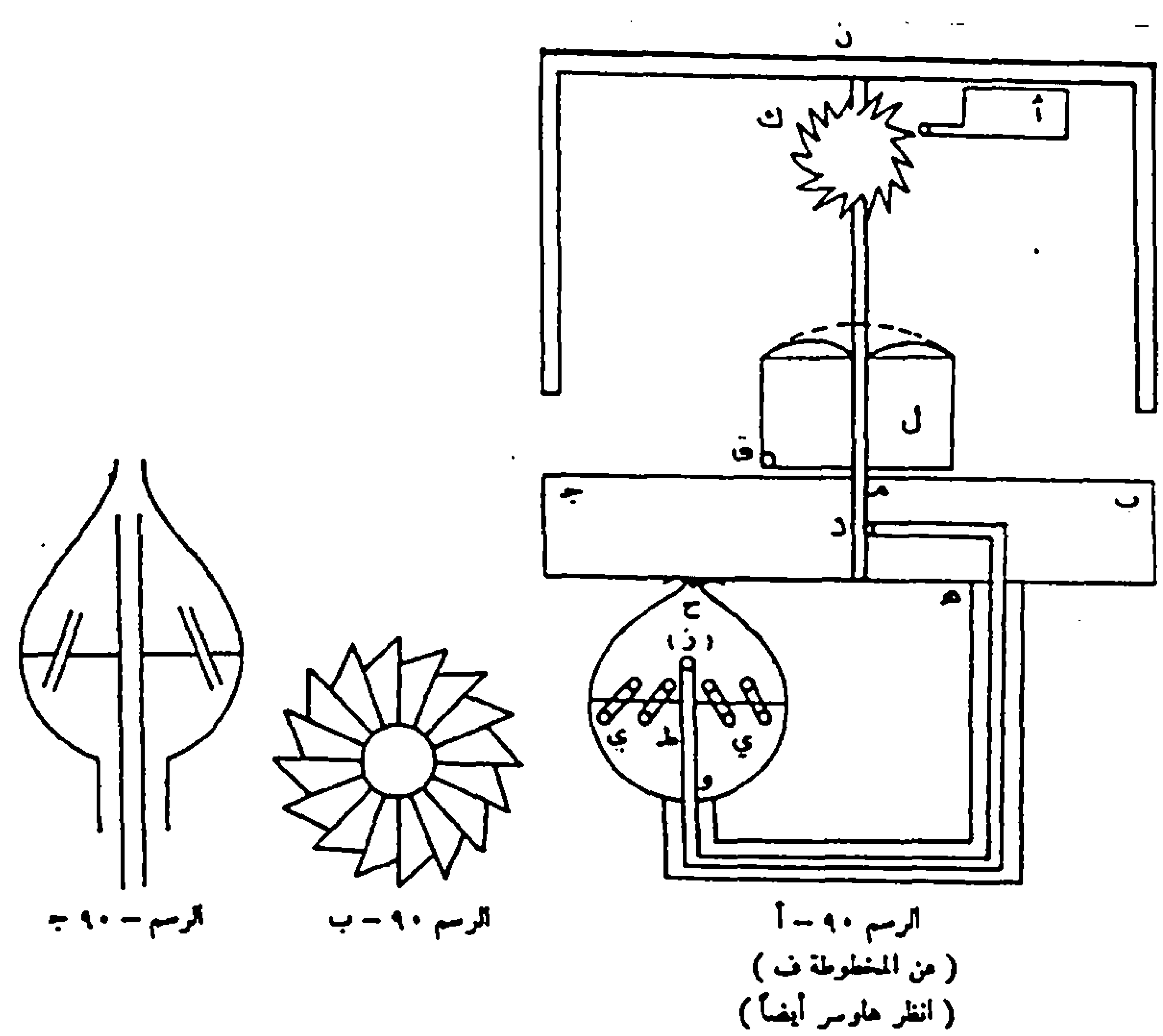


Figure (29). The reconstruction of Banu Musa drawing by al-Hassan.

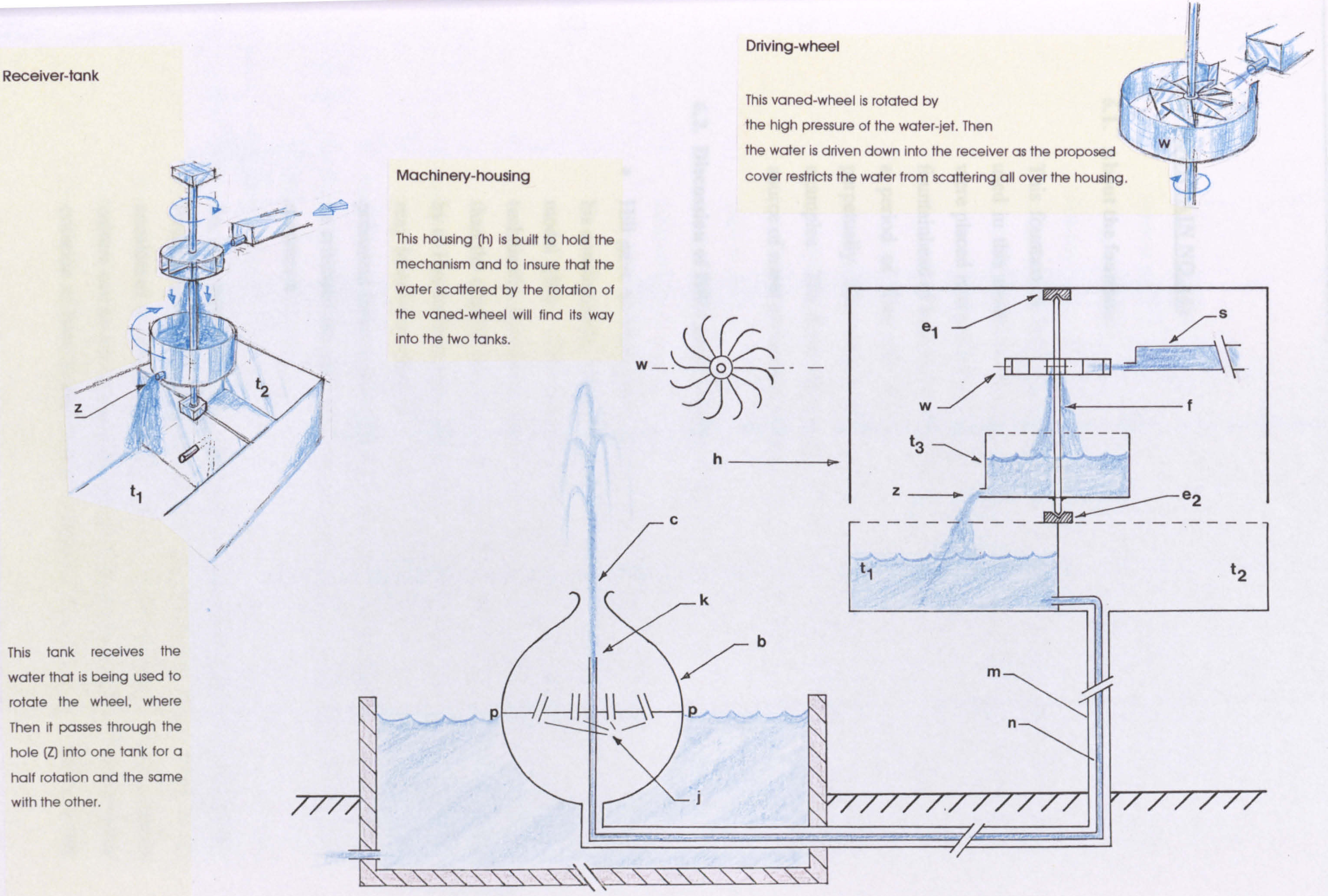


Figure 30:

This detailed modified drawing clarifies the obscurity of the fountain mechanism.

6. FOUNTAIN NO. (4)

6.1. About the fountain.

This fountain is, basically, a double version of Model 89. The mechanism used in this model is for operating two bodies of fountain. Both fountains were placed in one pool or they may have been separated into two pools. The fountainhead of both fountains produces in succession the shape of a shield for a period of time and changes to a lance for the same period of time perpetually. The erection of the fountain device is the same as the previous examples. The drain setting and the proximity of the fountain to a current source of water are essential principles.

6.2. Discussion of Hill's and al-Hassan's works.

- Hill gave no explanation notes on this particular model. He summed up his conclusion by mentioning that the model is simply a doubled version of model (89). The reproduced drawings of both Hill and al-Hassan, technically, provide no clearer understanding of the operation of the device than the original one (figures. 31, 32, 33). However, the modified drawing by al-Hassan does show the possible existence of another receiver tank that may have been attached to the pipe beneath the receiver-tank, which was presumed to have delivered water into the feeding-tank (t2). Furthermore, he criticised the very long pipe as being an obstacle to the balance-arm's movement.

- So, this model has been regarded as a doubled version of Model 89. Possible modifications therefore, that may have been added, ought to be considered in conjunction with two main factors involved. First, a design culture can be drawn from the nature of Banu Musa work. The distinctive criterion of Banu Musa's design concept is that they always tended to use each mechanical concept in a single fountain, and apply it to a doubled version with slight modification. Therefore, quite often, a brief description, along with reference, was given to a similar concept used in previous devices. Secondly, the crudeness of the drawings accompanied with the exaggeration in scale and proportion, make major modifications of a doubled version less likely.

- Figure (34) is a drawing from a fragment of a manuscript I have unearthed (mentioned earlier) and shows the same concept of this Model with a single difference on the imbalance-tank. Despite the fact that the drawing as well as the description given are both extremely poor, I confidently affirm that the concept of this model is exactly the same as the that was used in Model 89, although it is a doubled one. In addition, Banu Musa did not mention any modification regarding the long pipes attached to the balance-pipe. Therefore, evidently, the construction of the device mechanism is the same as that applied to Model 89. As a result of these assertions, the additional receiver tank suggested by al-Hassan, and the very long pipe attached to the balance-pipe shown in Banu Musa's work are to be ignored.

6.3. Construction of the fountain and its device.

Since the construction of this fountain is the same as Model 89, I shall not repeat it here, except the pipe arrangement, which is as follows; Wide pipes (k, m) are linked to the bottom of each tank stretching along the way down to the inlet of each fountain (fig. 35). A thinner pipe (l) is inserted through pipe (k), where one end terminates at the fountain-head of the fountain (2) and the other end penetrates the partitioning wall into tank (t2). Similarly, pipe (n) starts from tank (t1) penetrating the partitioning wall between the feeding-tanks into tank (t2) down through pipe (m), and then up to the fountain-head of the fountain (1).

6.4. How the fountain operates.

Water flows from supply-channel (s) into the receiver-tank (c), running through the balance-pipe (d), from which water descends into the feeding-tank (t1). Meanwhile, bleeder pipe (h1) tips into the imbalance-tank (y). From tank (t1) water runs into two pipes at the same time, through the narrow pipe (n) which terminates at the fountain-head of the fountain **(1)** emitting the shape of a lance. Water also flows into pipe (k) which deposits water into the lower part of the fountain **(2)**, from which water passes through jets (j) into the upper part of the fountain, flowing-out through the fountain-head to produce the shape of a shield. This session lasts for the period that is takes to fill up. the imbalance-tank (y). The balance-pipe tilts downward as imbalance is caused when water reaches a certain level in the imbalance-tank (y). Then water evacuates from the imbalance-tank (y) into the adjacent tank (x) through hole (z). From the other end of the balance-pipe, as the receiver-tank (c) rises up away from supply-channel (s), water starts to flow downwards into the next feeding-tank (t2). While water is being discharged from the imbalance-tank (x) through the bleeder (h2), pipe (m) delivers water from tank (t2) all the way down into the lower part of the fountain **(1)**. Water forces its way through jets (j) into the upper part of the fountain, flowingout through the fountain-head to produce the shape of a shield. At the same time, water passes through pipe (l), which terminates at the fountain-head of the fountain **(2)** emitting the shape of a lance. As water is discharged from imbalance-tank (x) through bleeder (h2), the balance-pipe returns back to its horizontal position and the motion is repeated perpetually.

The interval primarily coincides with two factors, which are the filling time of the suspended imbalance-tank (y) and the equivalent period of the evacuation of water from the other adjacent tank (x).

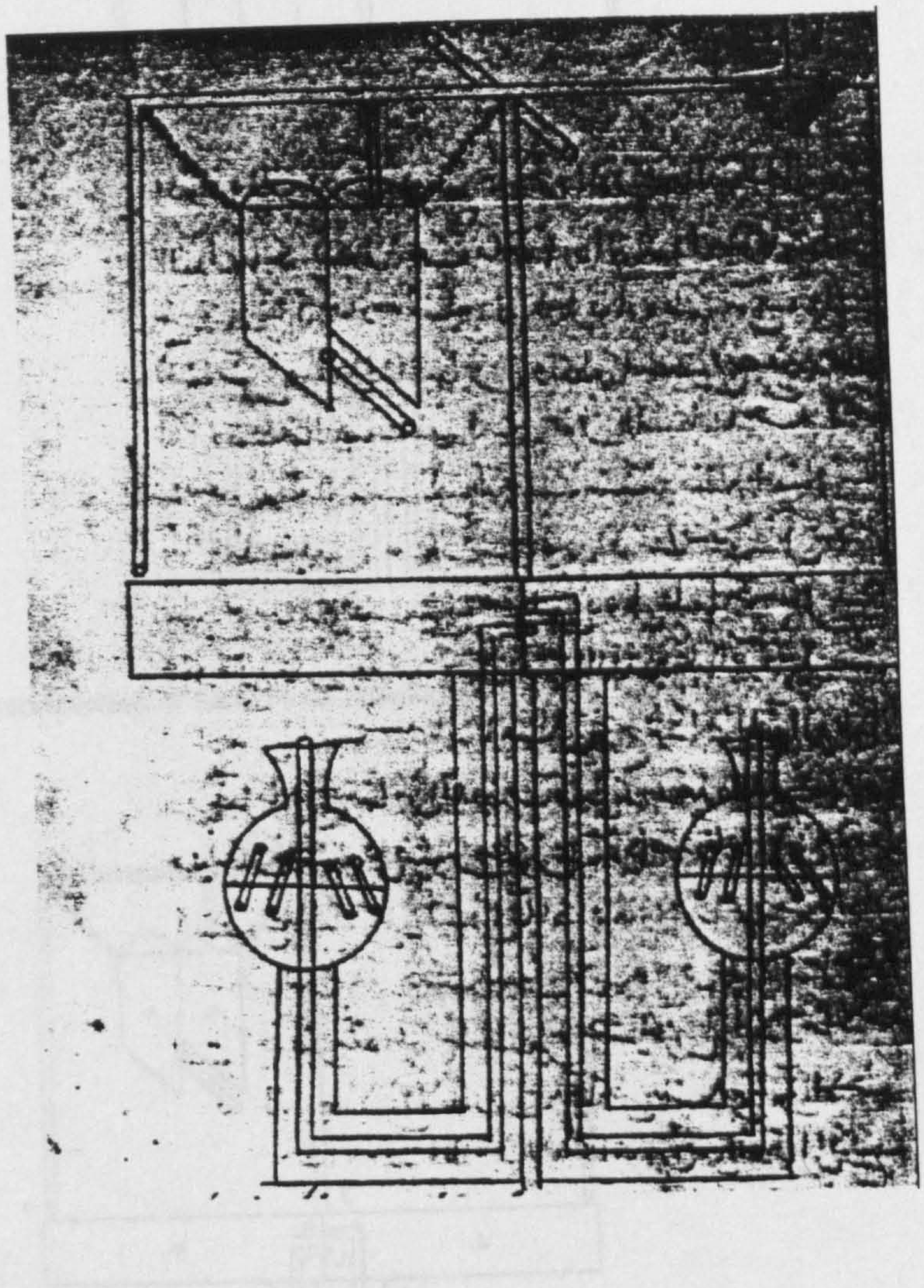


Figure (31) Banu Musa drawing which appeared in Hill's book.

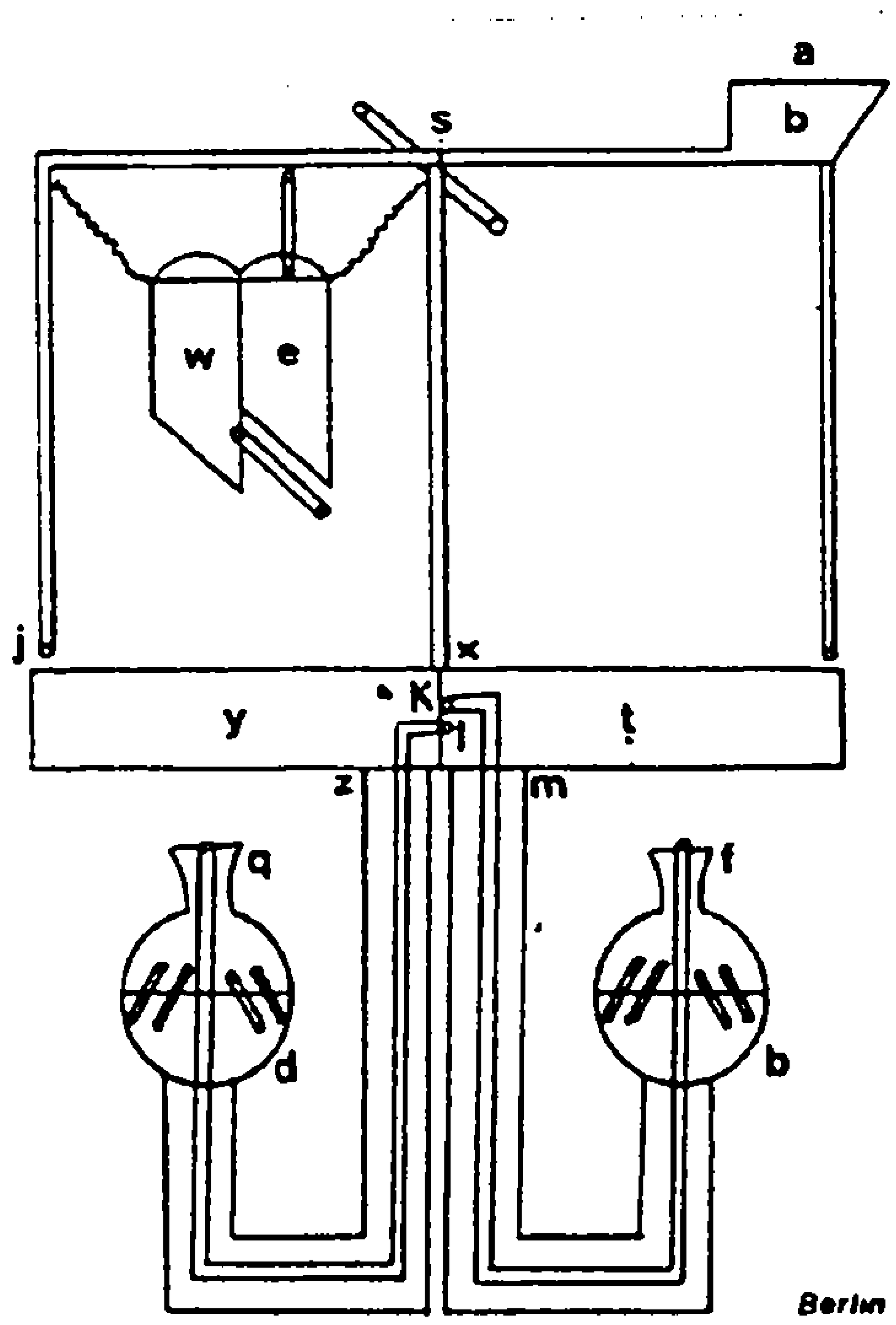


Figure (32). Hill's reconstruction of Banu Musa drawing which is still unclear.

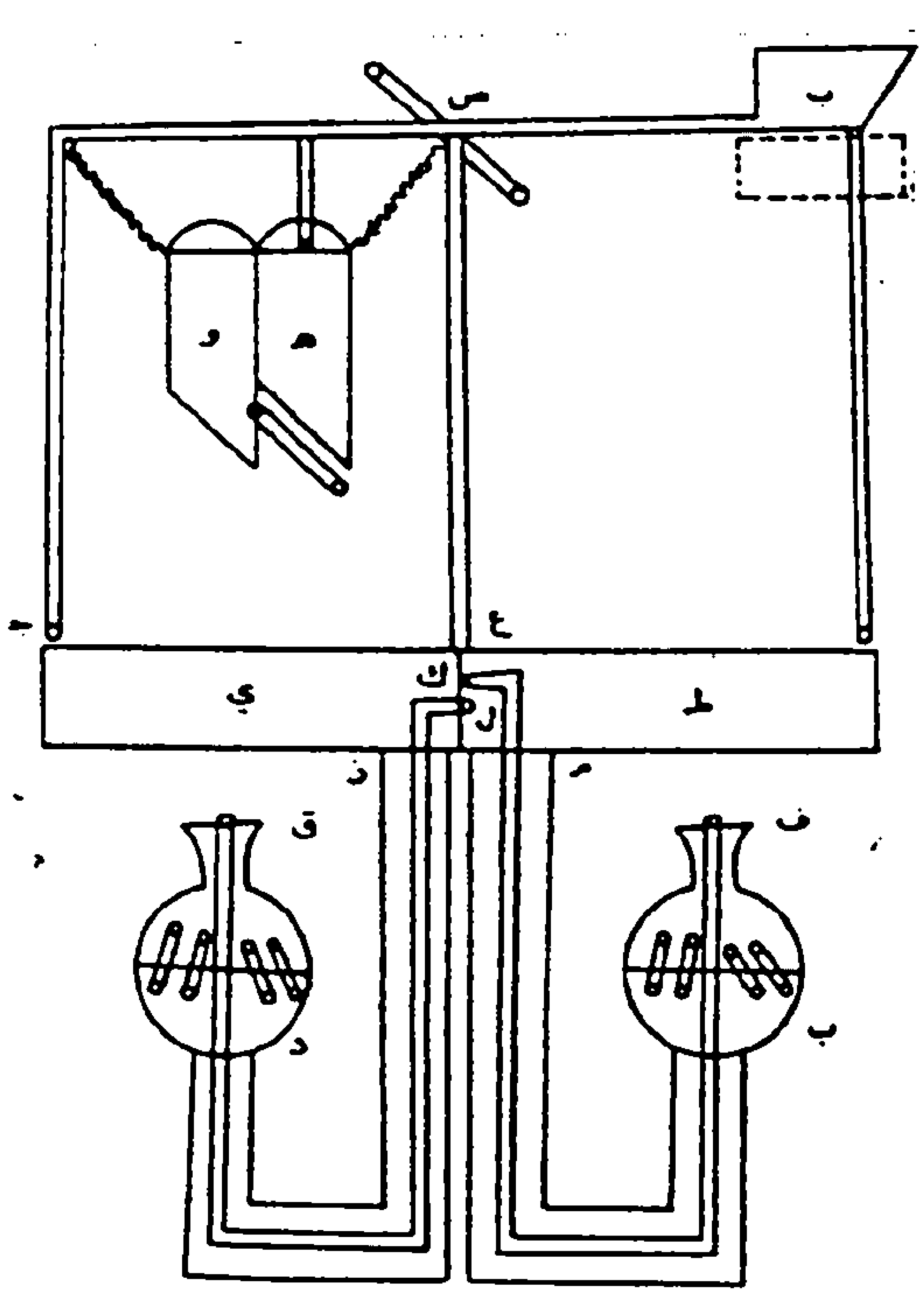


Figure (33). Al-Hassan's reconstruction of Banu Musa drawing which shows the proposed tank, in doted lines.

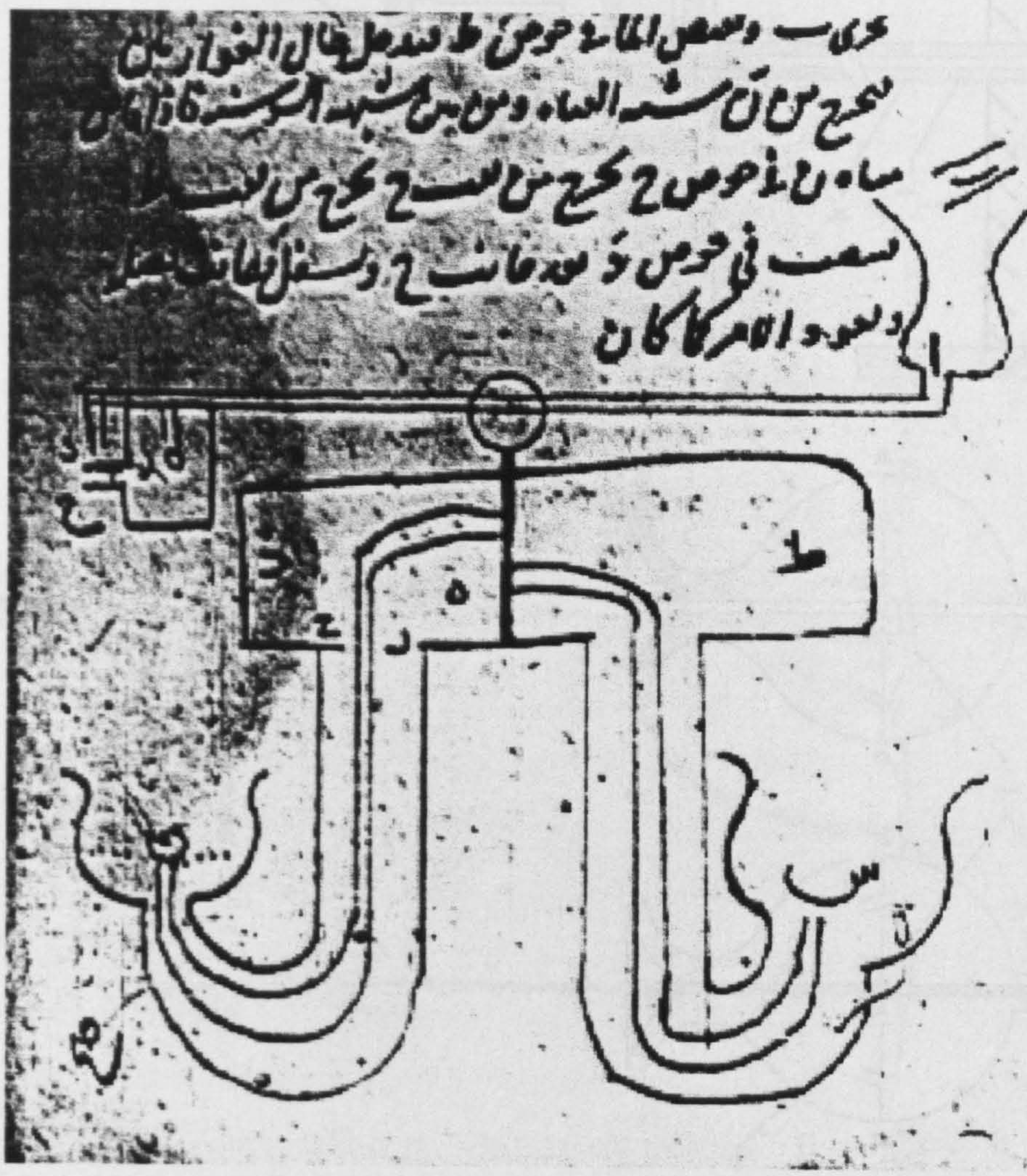
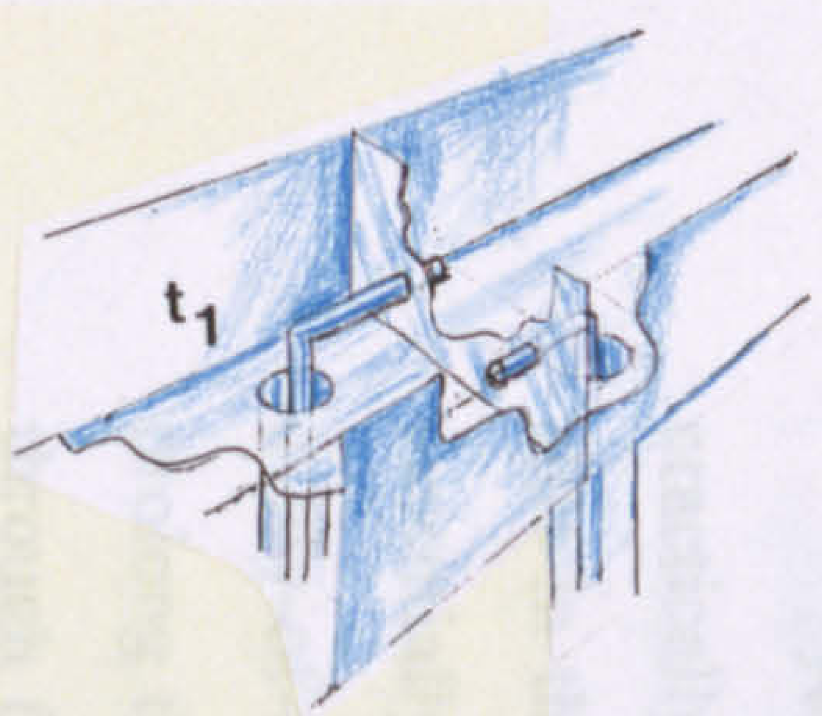


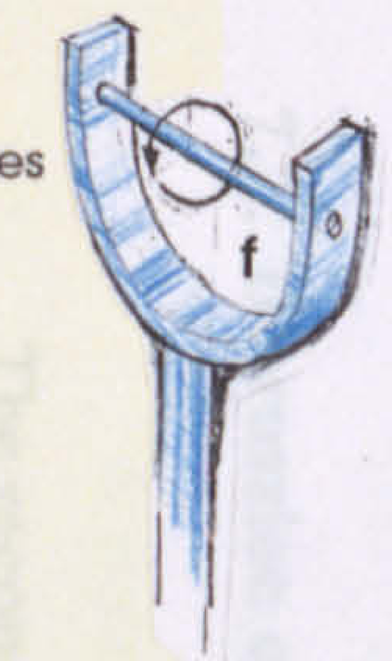
Figure. (34) A drawing of the fountain from The John Rylands University Library

(Arabic Ms 351 [419], section B)



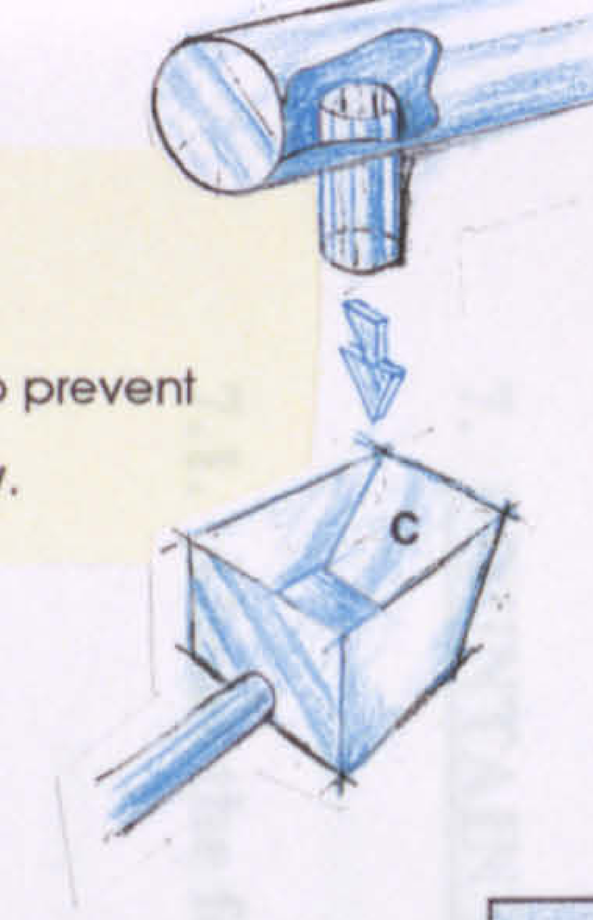
Pipe arrangement

The size of the pipes is worked out in accordance with the size of the feeding-tank and the fountain-head.



Fulcrum

An axle rotates smoothly in two bearings to give a flexible movement to the Balance-pipe that is attached to it.



Supply-channel

The upstanding pipe is arranged to prevent impurities and provides steady flow.

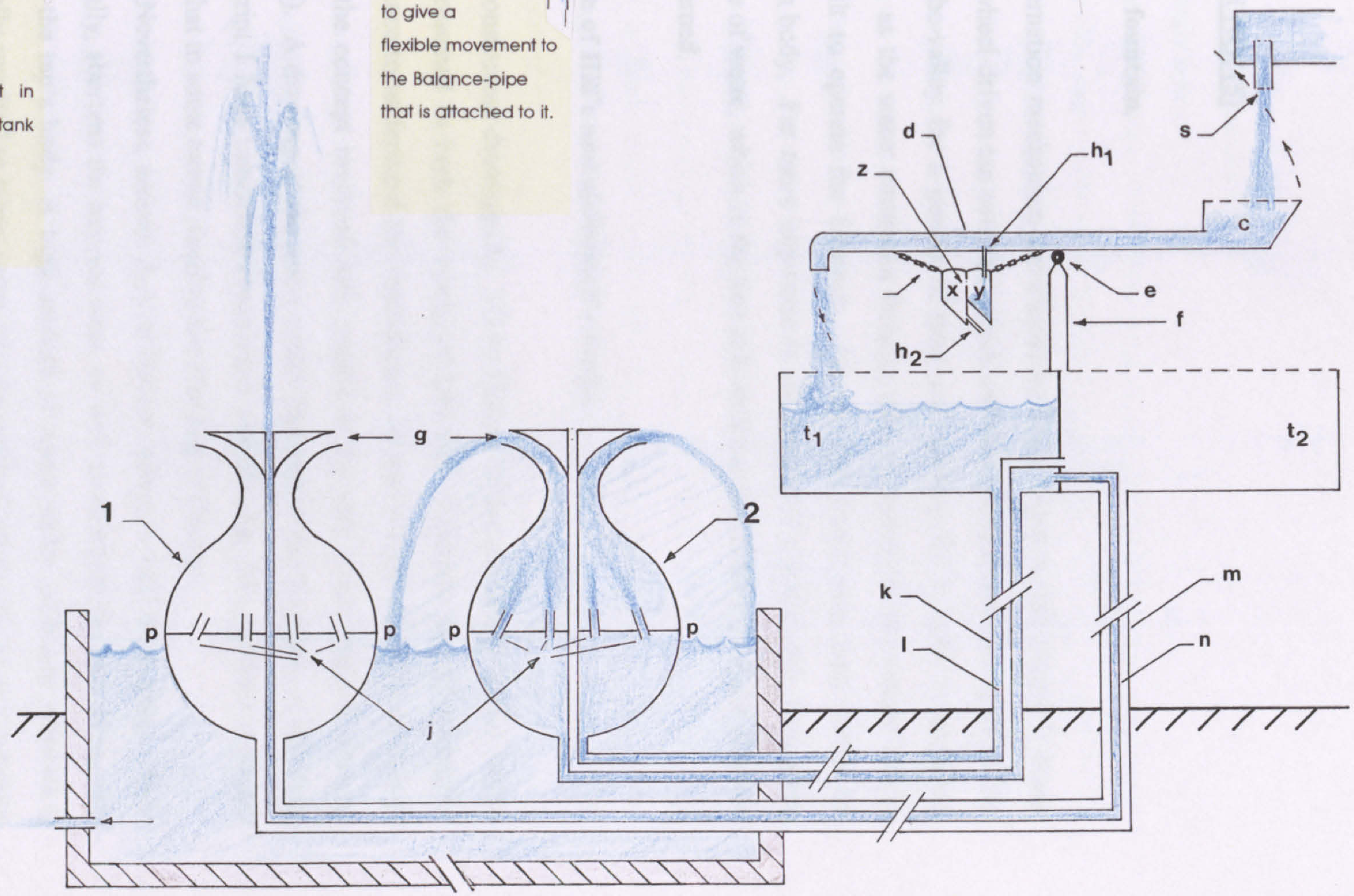


Figure 35:

In this modified drawing the principle of the mechanism is utterly the same as in Model 89.

7. FOUNTAIN NO. (5)

7.1. About the fountain.

The alternation mechanism introduced by Banu Musa in this Model is based on the wheel-driven tap concept, which controls the emission of a shape of the lily-of-the-valley for a period of time and equally, for a lance in perpetual fashion, as the water continues flowing into the fountain. No remote device was built to operate the fountain. Instead the device was built inside the fountain body. Far more important is the setting of a sufficiently high static pressure of water, which is the key role as far as the operation of the fountain is concerned.

7.2. Discussion of Hill's and al-Hassan's works.

The reconstructed drawing (fig. 37) by Hauser of this particular Model, which are represented in both the works of Hill and al-Hassan are of substantial importance to understand the mechanism. It was a huge effort by Hauser to define the concept involved with regard to the very crude original drawing (fig. 36). A drawing of the same model depicted in the fragment of the same manuscript I have unearthed (mentioned earlier) (fig. 38), portrays a clearer image that to some extent matches the drawing of Hauser.

Nevertheless, section A-A of Hauser, shows a very small plug, which, practically, shortens the interval time, as well as affecting the size of the two slits in the tap's body. A high amount of water under sufficient pressure is essentially required to inject water into the inclined pipes (j2) for it to produce a lily-of-the-valley. Therefore, a wider diameter plug is more practical to prolong the interval time, and to allow an adequate amount of water to pass through (fig. 39). On the other hand, the drawing shows a relatively small cone shape fountainhead, which by no means would produce the lily-of-the-valley as Banu Musa described in other examples.

7.2. Construction of the fountain.

- Fountain body:

  A spherical shape forms the fountain in which the device is located. A cone-like shape with a jar-like-orifice opening forms the fountain-head (fig. 39). The body is divided into four sections, by three horizontal plates. The first partitioning plate (mm) is set close to the bottom where inlet (g) is located and various perpendicular or inclined jets (j1) occupy its surface to serve the purpose of rotating the vaned wheel (w1) in the above chamber (b). Plate (nn) creates the top surface of the chamber (a).

- Vaned-wheel

  On the centre of plate (mm) inside chamber (b) an axle is erected (f) that rotates in two bearings (e1, e2). To the lower part of axle (f) a vaned wheel (w1) is fixed close to the jets (j1), through which water surges and impinges on the wheel vanes. On the upper part of the axle worm-gear (c) is attached.

- The Wheel-driven tap:

  To the worm-wheel tap (t) of a double-slitted seat is linked. In the plug of this tap slit (u) aligns with one of the slits in the seat, as the worm-wheel (w2) rotates (fig. 39). To the two slits in the seat two pipes are connected, one of which (d) terminates near the top of the fountain, and the other pipe (h) deposits water into the upper chamber (a). On plate (qq), which is the top surface of chamber (a), various inclined-pipes (j2) are erected, through which water flows out to produce the shape of a lily-of-the-valley.

- Supply channel:

  Pipe (s) deposits water into the fountain's body through its inlet (g). Water flows through this channel and is led either from a higher tank or directly from a current source so that a high static pressure of water is obtained permanently.

7.4. How the fountain operates.

Water enters through inlet (g) and surges through pipes (j1). These jets rotate the vaned wheel (w1) in chamber (b). As the axle rotates the worm (c) turns, which in return rotates the warm-wheel together with the screw of the tap (t). When slit (u) in the plug of the tap (t) is opposite the opening in the body of the tap that coincides with pipe (d), water flows through this pipe and the fountain emits a vertical jet. As the plug of the tap continues to rotate, bringing slit (u) in line with the second opening in the tap's body that coincides with pipe (h), the emission of the vertical jet ceases and water enters the upper chamber (a). Then water passes through the inclined jets (j2) and the fountain produces a lily-of-the-valley for the same period as the vertical jet. This operation is repeated as water continues to flows through the fountain's inlet.

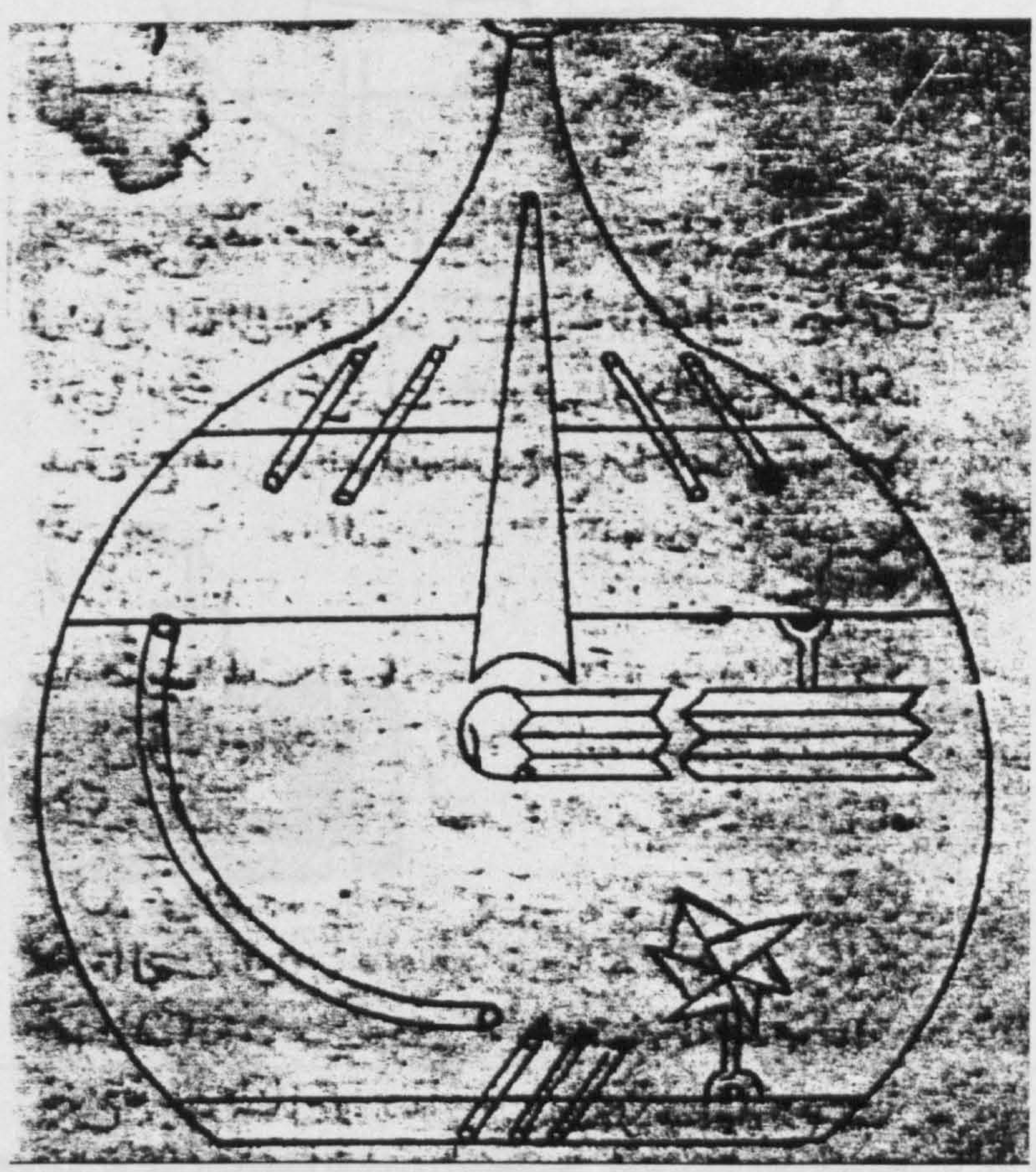


Figure (36). A reproduction of the drawing of Banu Musa that Hill referred to in his book.

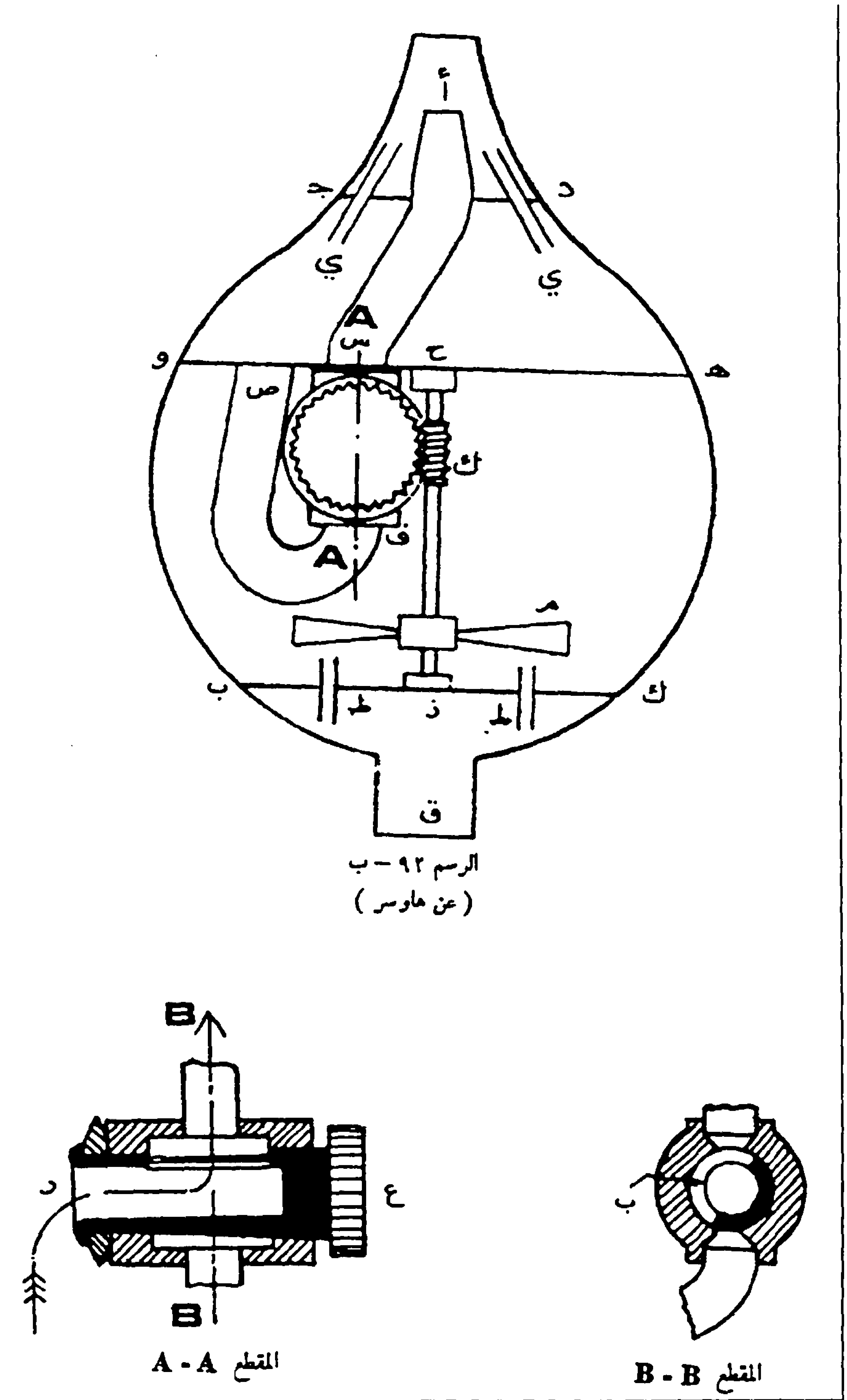


Figure (37) A reproduction of the modified drawing by Hauser, which are represented by Hill and al-Hassan.

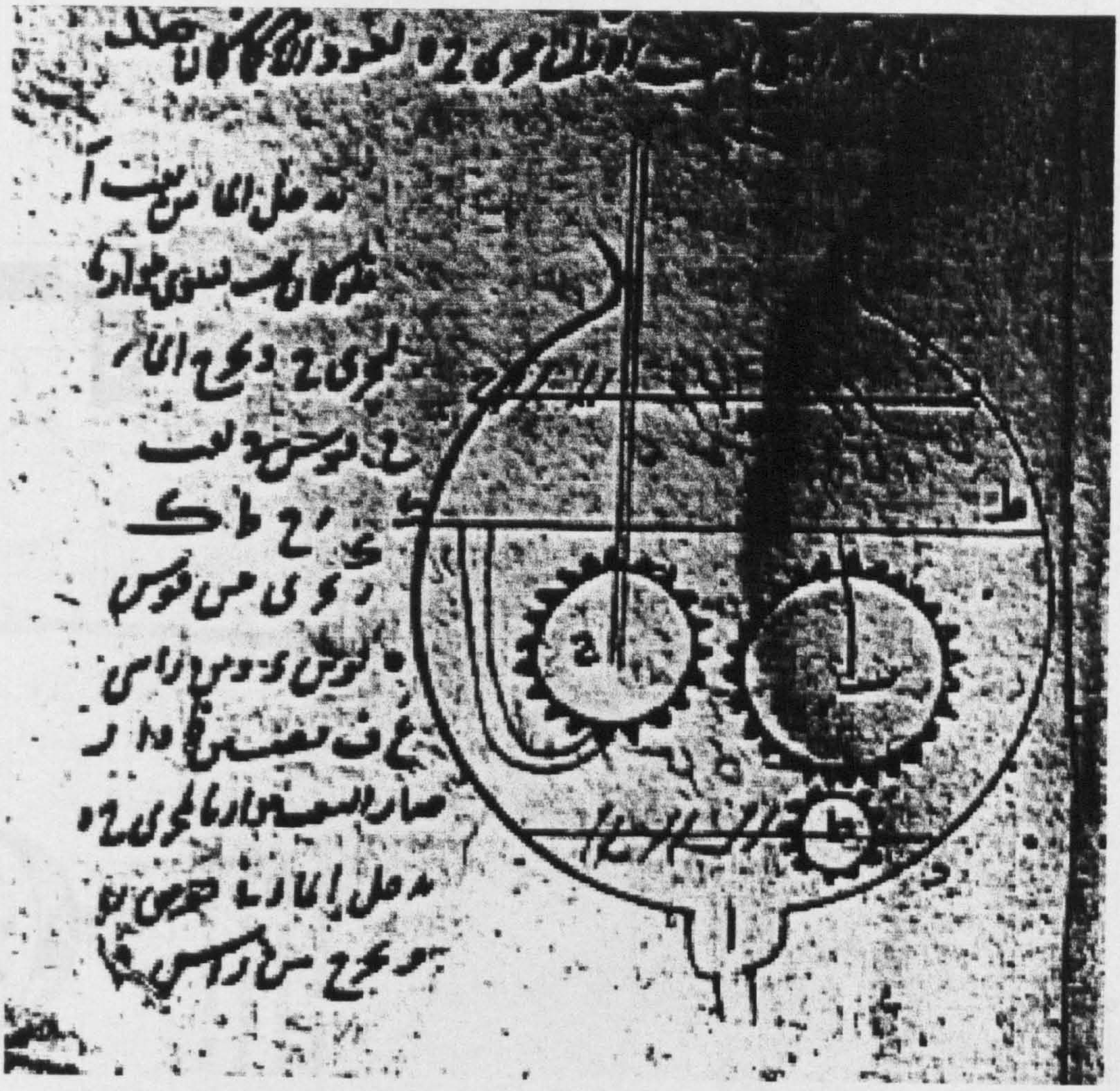


Figure (38). A reproduction of the fountain drawing from The John Rylands Library (Arabic Ms 351 [419], section B). This drawing is the closest to the modified drawing by Hauser.

Figure 39: This drawing explains in details the complicated mechanism used in this particular model.

8. FOUNTAIN NO. (6)

8.1. About the fountain.

The mechanism of this fountain is similar to that of Model 92. Here two other small fountains were attached to the main fountain in which the mechanical device is built. The main fountain changes the emission from the shape of a shield to the shape of a lance in alternation with the adjoining two small fountains. This fountain in particular has a rather complicated pipe arrangement. Banu Musa proposed different shapes of emissions to be produced from the fountain-heads. So instead of a shield shape, a Lily-of-the-valley's shape can be obtained by modifying the fountainhead of one or all of the three fountains.

8.2. Discussion of Hill's and al-Hassan's works.

Hill had given no satisfactory explanation on the operation of the fountain. The drawing he reproduced was no more than a reproduction of the original drawing, with Latin lettering (fig. 40, 41). He seemed to have avoided studying the model in detail, leaving the vision between the text and drawing unclear.

We find a clearer explanation of the operational mechanism of the fountain provided by al-Hassan (fig. 42). He proposed a number of modifications on the drawing, which were based on Hauser's work and correspond with the description given by Banu Musa.

Yet this modified drawing is, to some extent, poor and basically unsound as far as the flow of water within the fountain is concerned. Furthermore, the proposed principle of the fountain-head particularly, the part that produces the shield in the main fountain contradicts the design concept used by Banu Musa in the following aspects:

- Banu Musa had shown an engineering culture, and they always tended to refer to a previous example when describing a setting for a new model; even with some modification. In the case of the fountain-head, they obviously said that: "The example of that is that we repeat the picture which we described previously, and we repeat exactly the construction in it". Therefore, we find the structure of all fountain-heads, which were set to produce the shape of a shield, lance, or lily-of-the-valley, are by no means the same.

- The inner diameter of the shield as shown in Figure 42 is much greater than the other similar examples. In addition, the location of the gap from which water is emitted, producing a shield, is very low and further down from the head of the vertical jet. It is so obvious that the wrong location of the gap will serve no function, especially when the fountain is partially submerged in a pool or a basin.

- A continuation of the concept of the fountain-head's construction by Banu Musa was shown in a crude drawing of a fragment of a manuscript – unearthed by the researcher- and inclined pipes erected on the upper partitioning plate were used in this particular model (fig. 43).

8.3.Construction of the fountain.

- Fountain body.

  A cylindrical body topped with a conical bottle-like fountain-head forms the main fountain **1** (fig. 44). Two small spherical fountains **2, 3** are of a similar construction to Model (89) and are attached to the main fountain. The body of the main fountain is partitioned into four sections by three partitioning plates (qq, pp, kk). The lower partitioning plate (qq) is set near the inlet for the same function as in the previous Model 92. Also the lower section [chamber] (b) has the same structure in which the machinery is placed. The upper section [chamber] (a) is determined by plate (pp) and the top plate (kk) on which a circle of inclined jet is erected; these jets allow water to surge up to the fountain-head. Inside this chamber (a) a small chamber (d) is centred.

- Pipe arrangement.

  From chamber (a) two wide pipes (m1, m2) are branched and led through the middle of the two adjacent small fountains where they narrow down and terminate at the fountain-head of each one. Three narrow pipes are branched from the inner chamber (d), the first pipe (v) vertically passes chamber (a) and terminates at the fountain-head of fountain 1. The other two narrow pipes (n1, n2) are led from either side of the chamber where they penetrate pipes (m1, m2) and then emerge through a hole on each wide pipe to deposit the water into the lower part of both small fountain.

- The Wheel-driven tap:

  The construction of the tap and its attached wheel is the same as the previous Model. Pipe (h), which coincide with the lower slit, is connected to upper section [chamber] (a). Pipe (g) that coincides with the upper slit is linked to inner chamber (d).

- Supply channel.

  The settings of the channel (s) and the requirements of the water's pressure are utterly similar to Model 92.

8.4. How the fountain operates.

The mechanism operation is exactly as that of Model 92. Therefore, we will skip this part and move onto the second part that deals with water movement inside all fountains. When slit (u) in the plug of the tap is opposite the opening in the body of the tap (fig. 44) that coincides with pipe (g), water flows into inner chamber (d), from which water passes through three pipes. The vertical pipe (v), in the main fountain that terminates at the fountain-head, emits the shape of a lance. The other two pipes (n1, n2) at the same time deposit water into the lower body of both small fountains. Then water flows out through the inclined jets (j3, j4) into the upper part of each small fountain to produce two shields.

An interval takes place when the plug of the tap rotates driving slit (u) in line with the opening (seat) in the tap body that coincides with pipe (h). Then water flows into chamber (a) from which water forces its way through three directions. Pipes (m1, m2) deliver water straight up to the fountain-heads of the two small fountains to produce two lances. Meanwhile, water surges through the inclined jets from the top surface of the chamber (a) into the upper section (the fountain-head) to produce the shape of a shield.

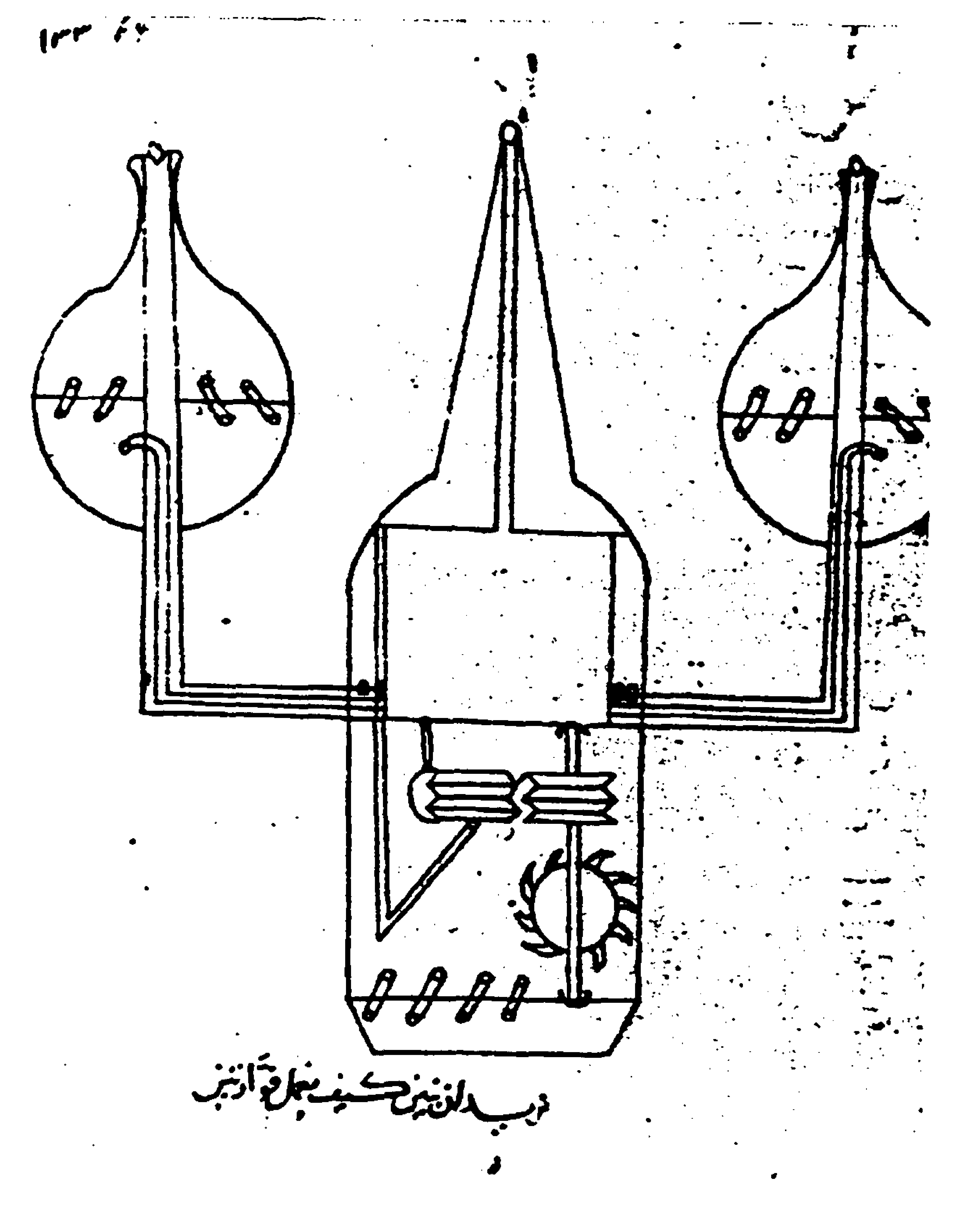


Figure (40) The drawing of Banu Musa that is reproduced in Hill's book.

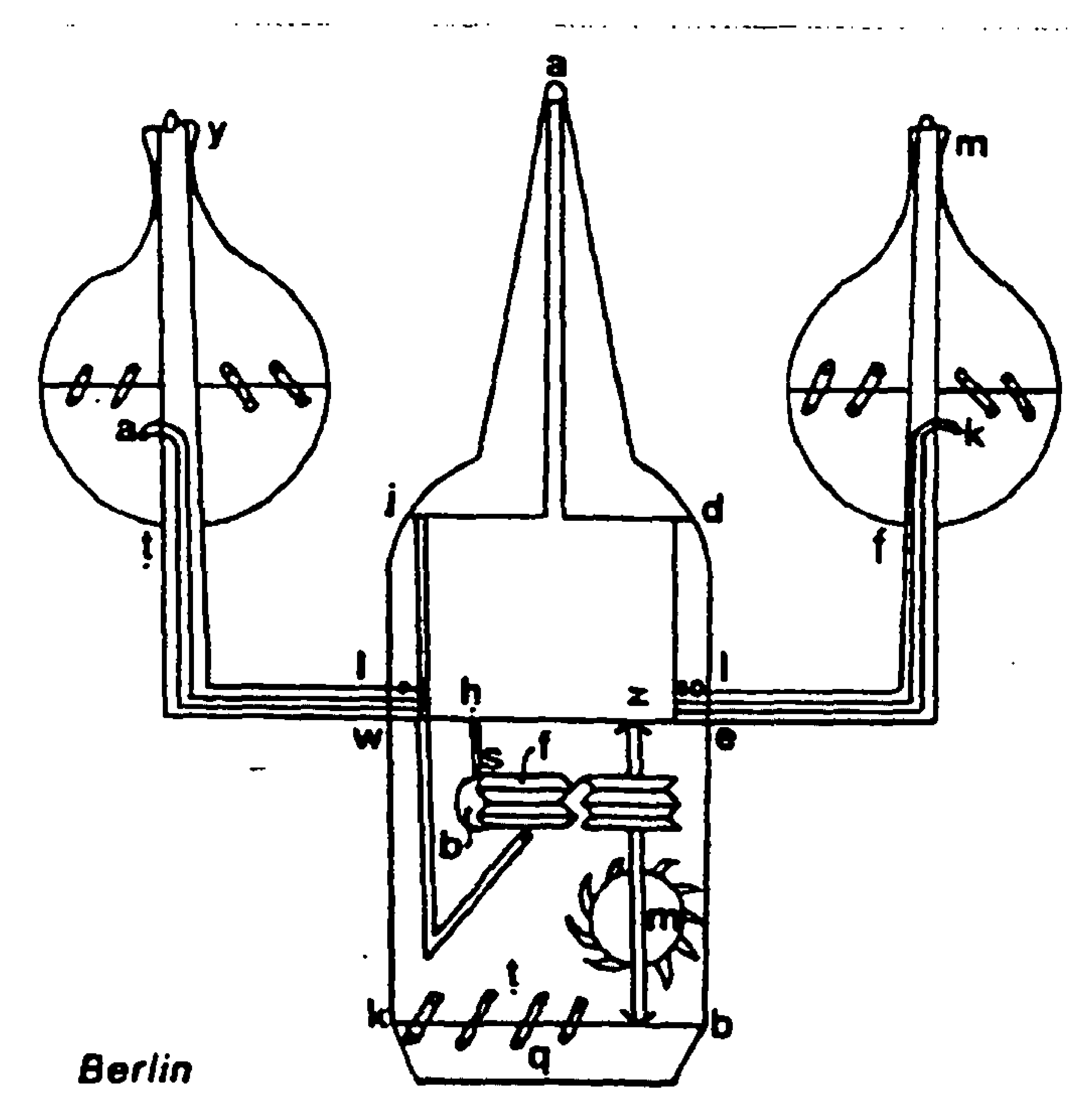


Figure (41) The reconstruction of the fountain's drawing by Hill.

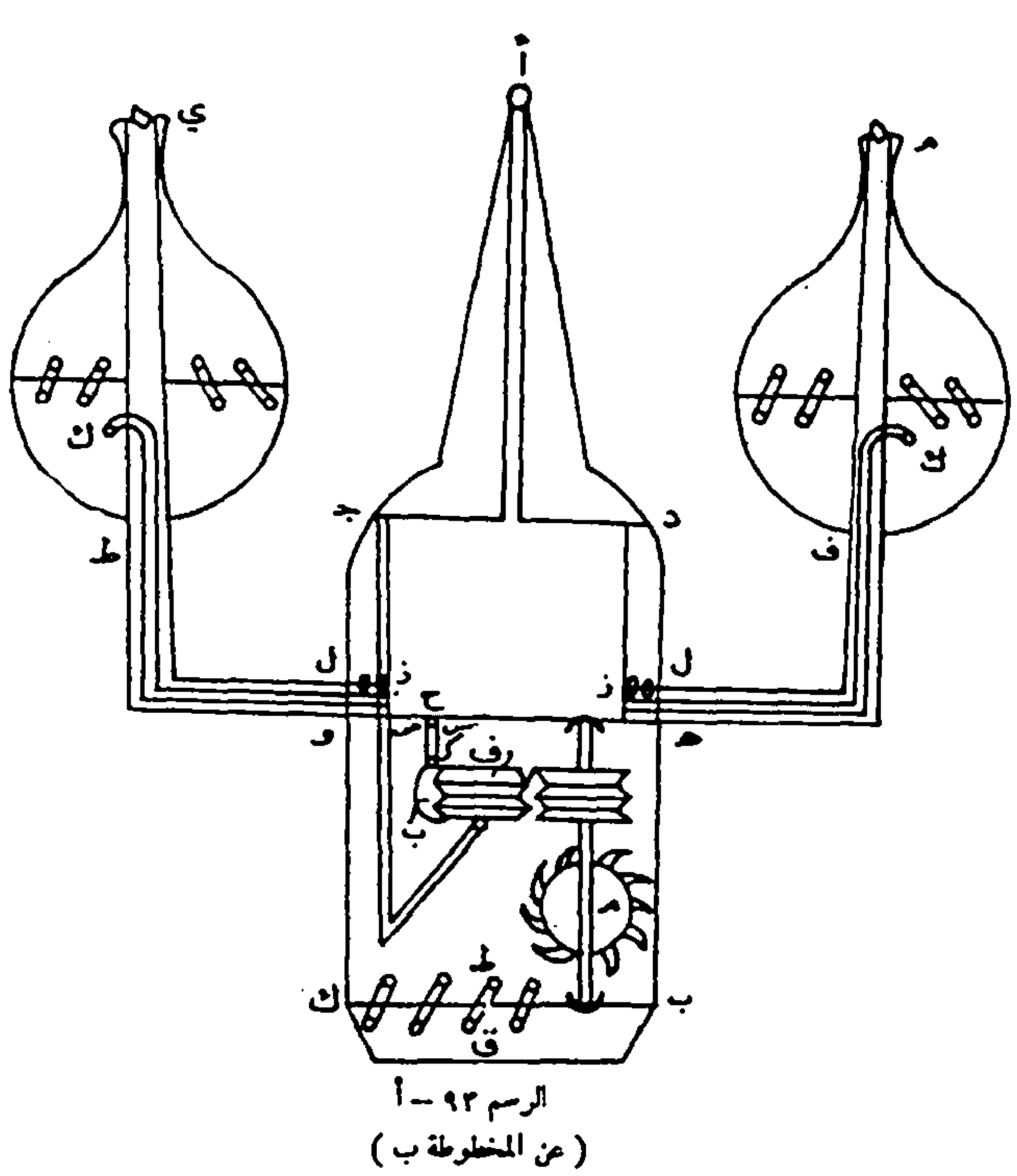


Figure (42). The reconstruction of the fountain's drawing by al-Hassan.

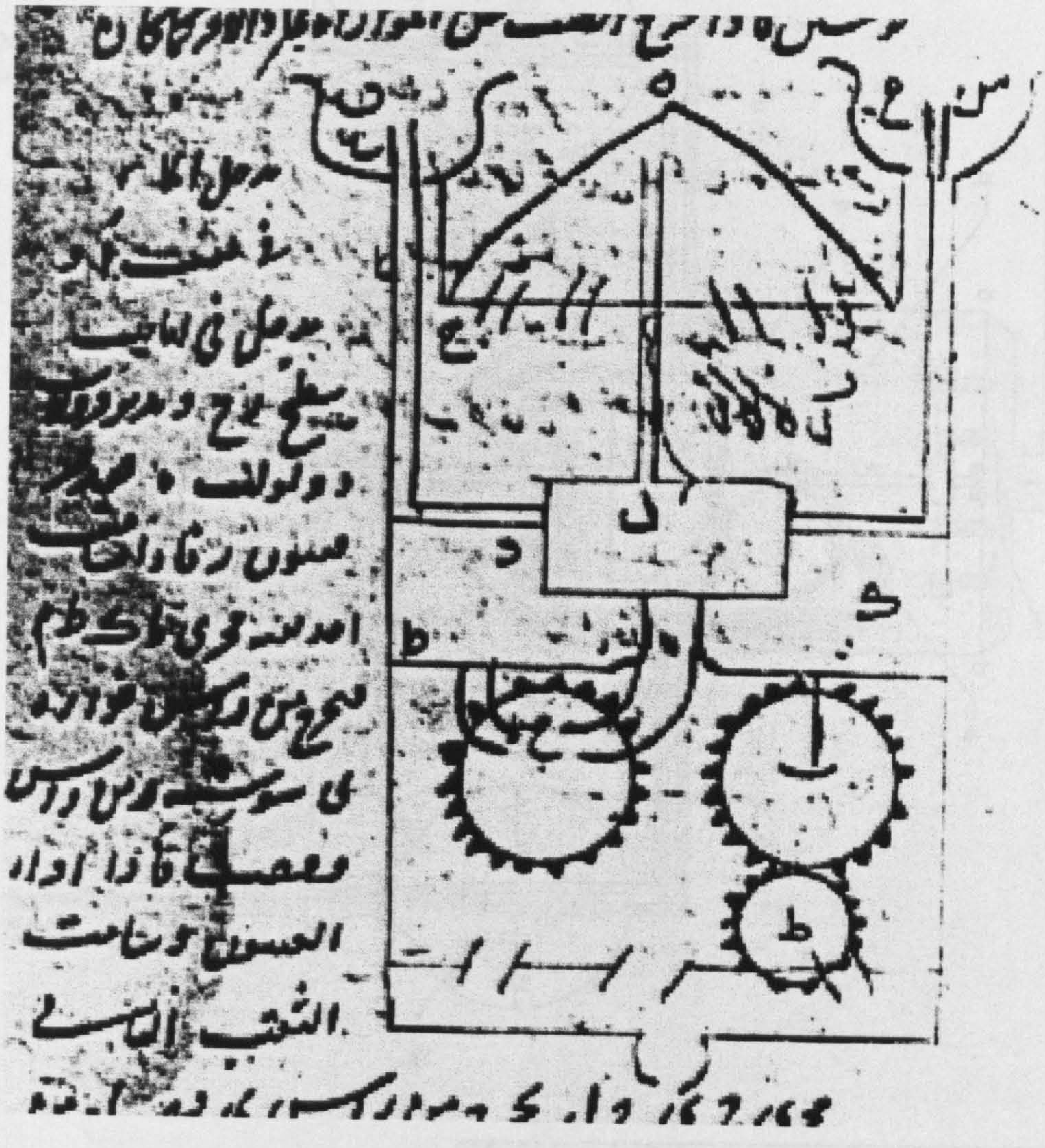
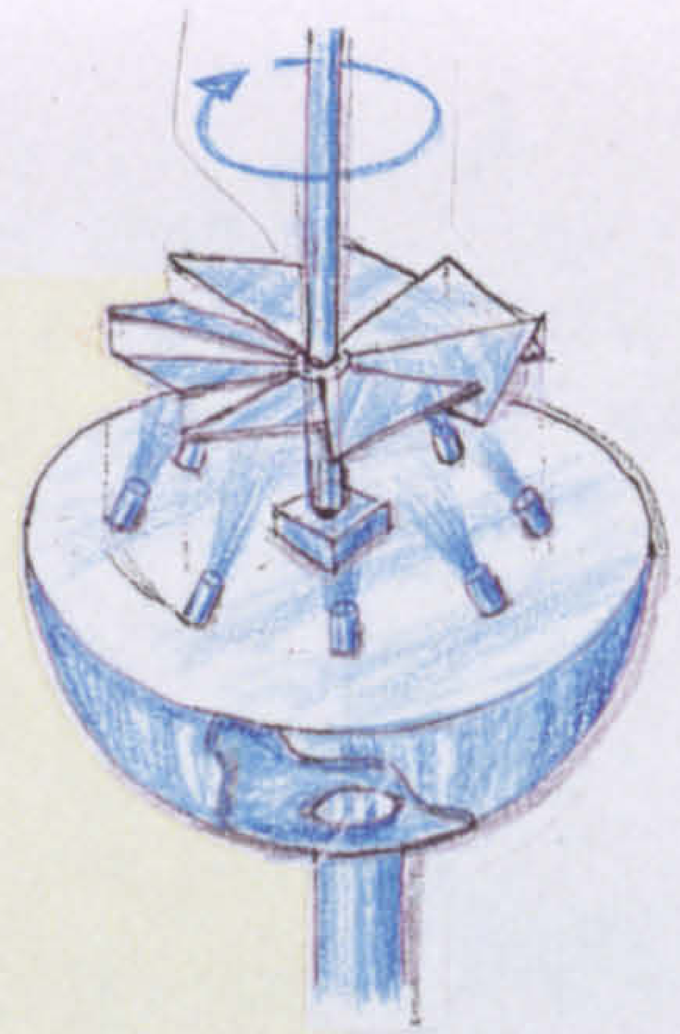


Figure (43). The drawing of the fountain from The John Rylands University Library (Arabic Ms 315 [419], section B).



Vaned-wheel

The rotation of this wheel is caused by the high-pressure of water that flows through a number of jets set on the floor of the chamber.

This vaned-wheel rotates in two, metal-to-metal, bearings.

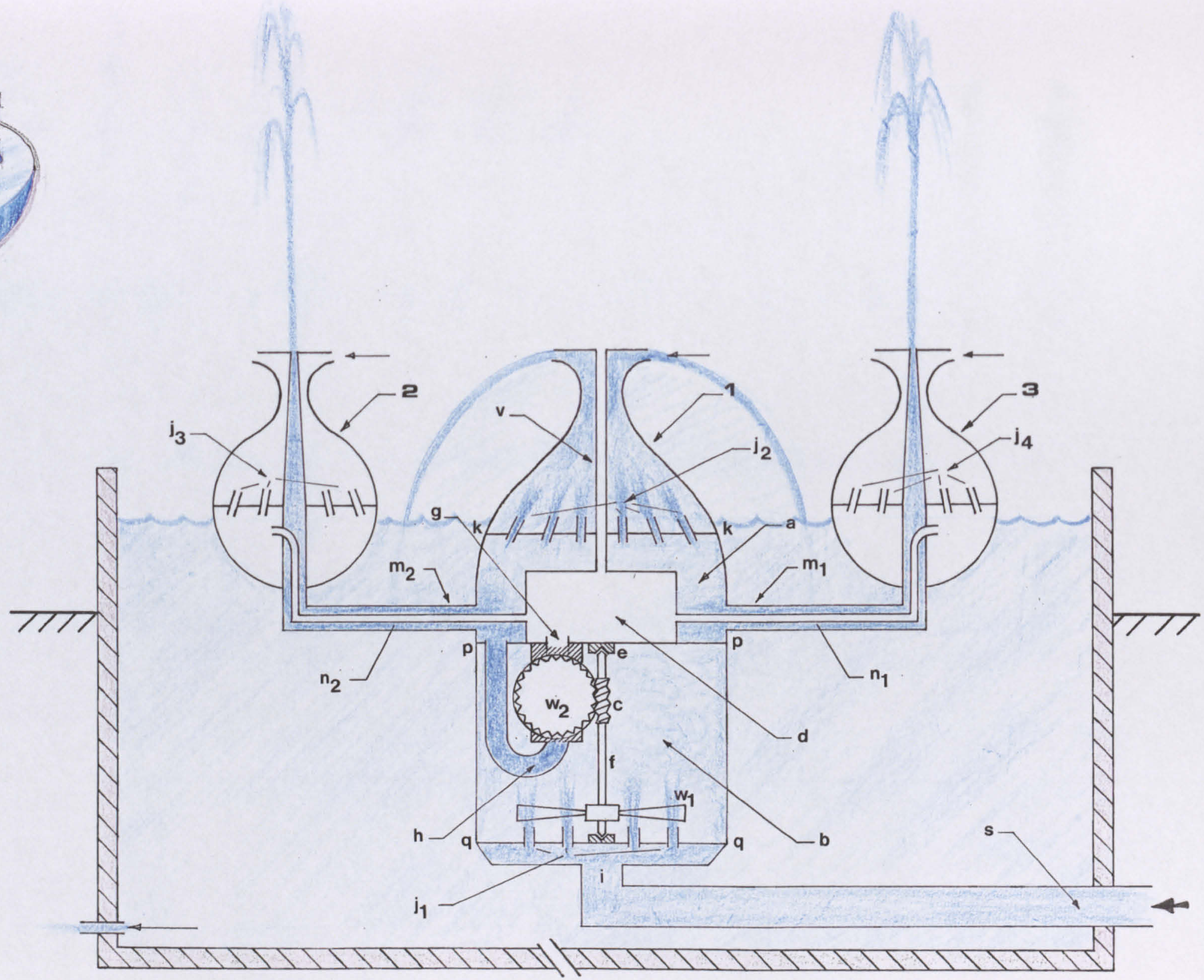


Figure 44: The modification I have introduced in this drawing gives a clear image of the fountain and its mechanism.

9. FOUNTAIN NO. (7)

9.1. About the fountain.

The operating mechanism of this fountain is the same as in Models 92 and 93. Here, a cubic housing was introduced in which the device was erected. This Model, as other similar one is considered as a single fountain despite the fact it may have contained two or more fountain bodies. Here two fountains were placed on top of the device and designed to produce the shape of the lily-of-the-valley and a lance for an equal period of emission, alternately. The device's housing and part of the two fountains were to be submerged in a pool or a basin (fig. 49).

9.2. Discussion of Hill's and al-Hassan's works.

- Hill, in this particular Model, avoided going in detail; he just offered a reproduction of the very poor illustration with the description of the original work that was presented in Banu Musa's book (fig. 45, 46). Al-Hassan, on the other hand, provided better-edited text, and a reproduction of the original drawing, with additional lettering (fig. 47). Technically, though, the reproduced drawing by al-Hassan gives no straightforward understanding of the mechanism that operated in the fountain; even with assistance from the accompanying text. Moreover, we find in the text some missing words and confusing sentences, which makes the mechanism considerably far from clear. However, it is very likely that the concept of the operation was clear to al-Hassan. It seems that al-Hassan may have avoided more involvement; particularly in the complicated description of the pipe arrangement described by Banu Musa. This was made no better by the misleading description of the device along with its confusing and crude drawing, which are notable for two main points:

1. The missing parts in the drawing, particularly in pipe arrangement inside both bodies of the two fountains made the drawing incompatible with the descriptive text. In figure 49, I have tackled this confusing part and have reconstructed the drawing in which the operation of the fountain becomes very clear.
2. The fountain-head of both fountains [1, 2] shows the setting concept for producing a shield, whereas the description given refers to the concept of producing a lily-of-the-valley.

- Figure 48, from the same manuscript I have indicated previously, shows the concept of producing the shape of a lily-of-the-valley in this model despite the very poor drawing. So this reinforces the fact that the concept applied will produce the shape of the lily-of-the-valley.

9.3. Construction of the fountain.

- Fountain device.

  Similar machinery to that in the previous Models is erected inside a cubic reservoir (a), which is divided into two sections by plate (pp), which is located near the inlet and serves a similar the function to that of a similar Model. The setting of this machine inside the housing is the same as the other Models, apart from the pipe arrangement.
- The two fountains.

  The construction of both fountains is the same as in Model 90. These two spherical fountains are erected on the top corners of the reservoir, opposite each other.
- Pipe arrangement.

  Two wide pipes (b, d) are brought together head-to-head and fixed at the upper slit (opening) of the tap (t). Pipe (b) is passed out of the reservoir and linked to the fountain [1] in which it penetrates the dividing plate and terminates near its fountain-head. The other pipe (d) is also passed out of the reservoir and connected to the bottom of the fountain [2]. On the lower slit (opening) of the tap (t) two narrow pipes with joined heads are fixed. Pipe (m) is led up to penetrate through pipe (b), and emerges from a hole in the lower part of fountain [1]. The second pipe (n) is led up also and passed through pipe (d) into fountain [2] where it terminates near the fountain-head (fig. 49).

9.4. How the fountain operates.

The mechanism of the vaned-wheel and the worm-gear is exactly as that of Models 92, 93, 94. Therefore, we will skip this part and move onto the second part that deals with water movement through the pipes and inside the two fountains. When slit (u) in the plug of the tap is opposite the upper slit in the seat of the tap (see details in fig. 49) that coincides with the combined heads of pipes (b, d), fountain [1] emits a vertical jet, as the water passes through pipe (b). At the same time pipe (d) deposits the water into the lower part of fountain [2] from which water surges through the small pipes (J3) into the upper part of the fountain to produce the lily-of-the-valley. As the plug of the tap continues to rotate, bringing slit (u) in line with the second opening, the lower slit in the seat coincides with the narrow pipes (m, n), and the fountain [1] produces lily-of-the-valley. This occurs as pipe (m) deposits the water into the lower part of the fountain from which water surges through the small pipes (j2) up to the fountain-head. Meanwhile pipe (n) delivers the water into fountain [2] to emit a vertical jet. The interval of the fountain continues changing over for an equal time as the inflow of water continues (fig. 49).

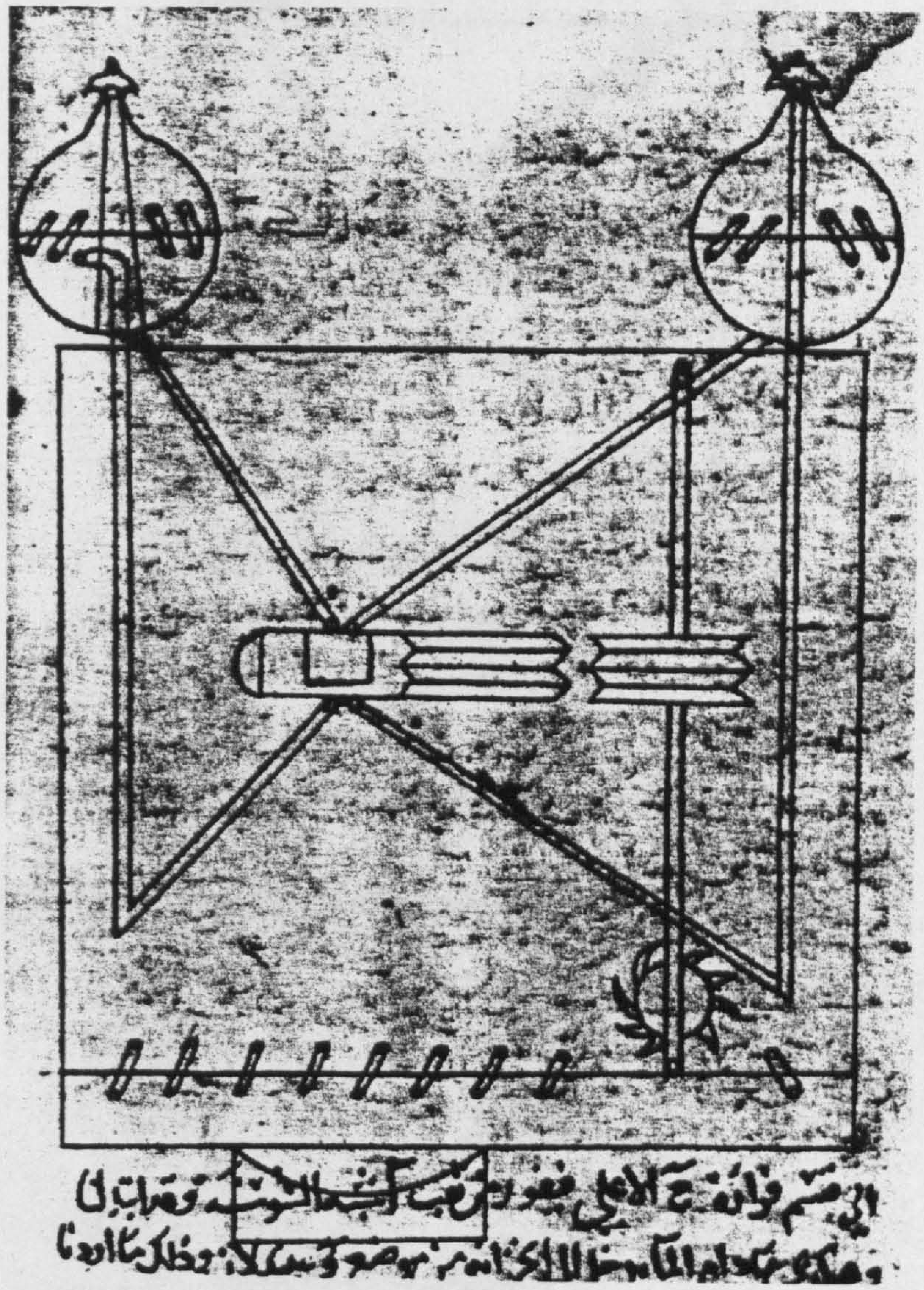


Figure (45) The drawing of Banu Musa as reproduced in Hill's book.

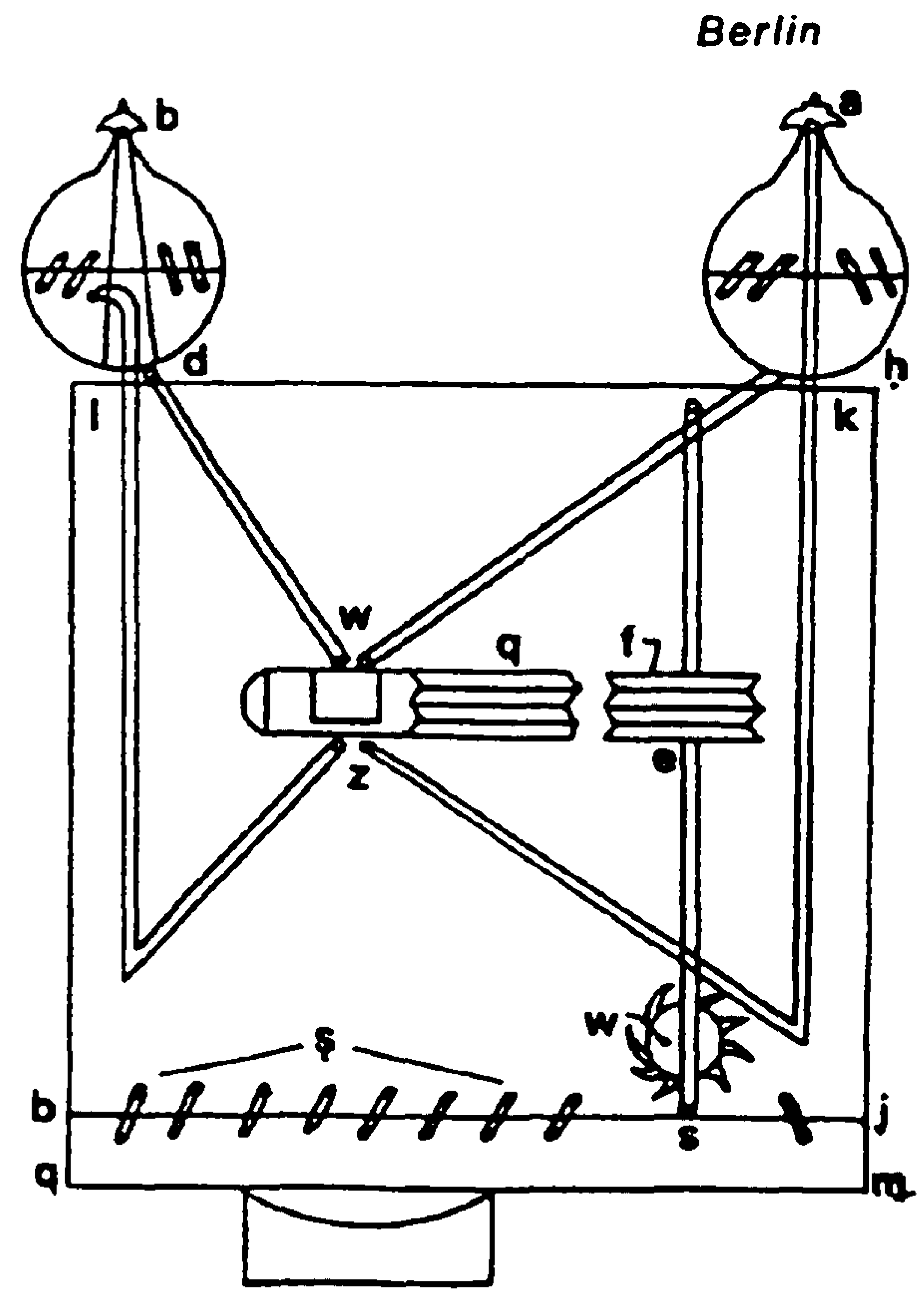
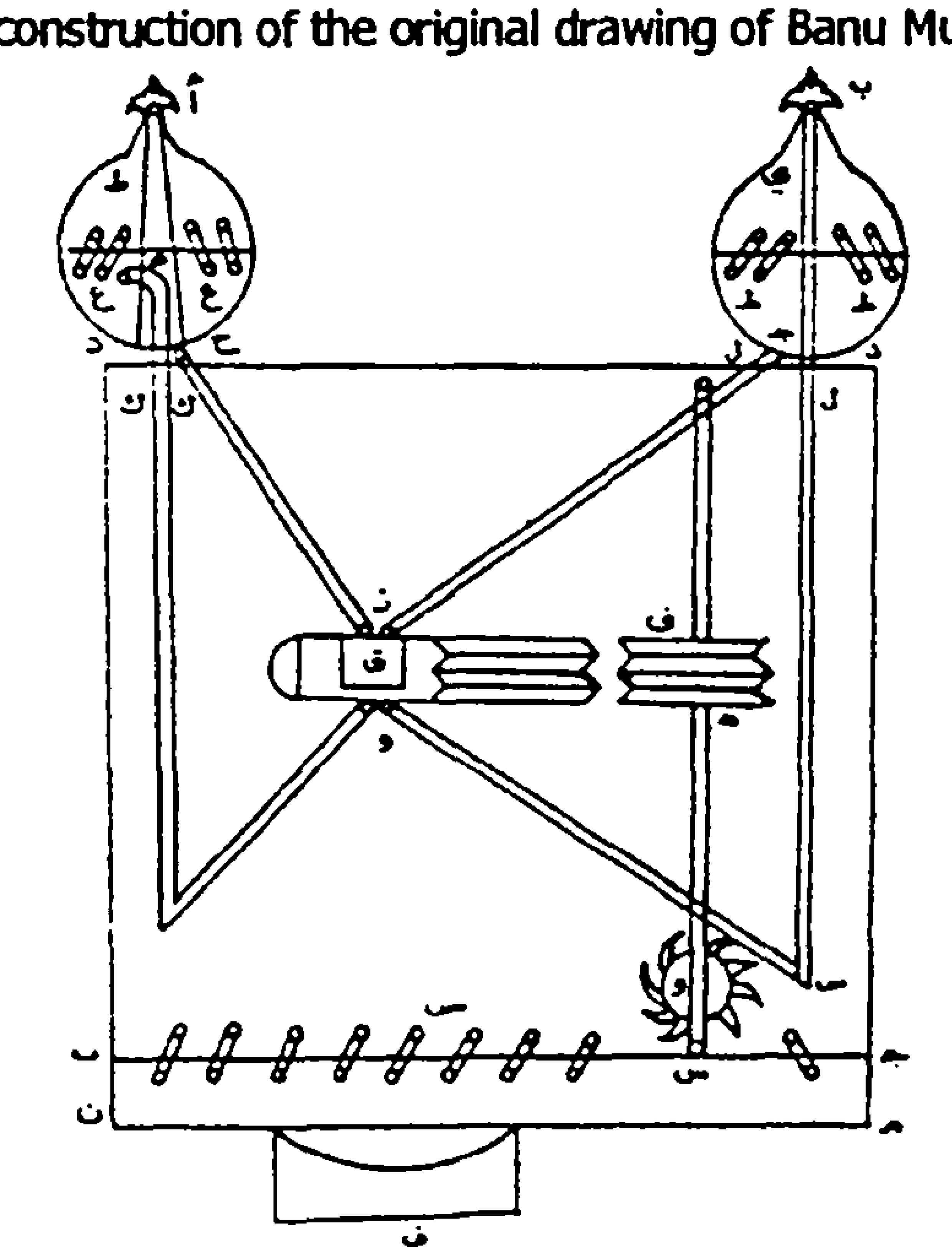


Figure (46). The reconstruction of Banu Musa drawing by Hill.

Figure (47). The reconstruction of the original drawing of Banu Musa by al-Hassan.



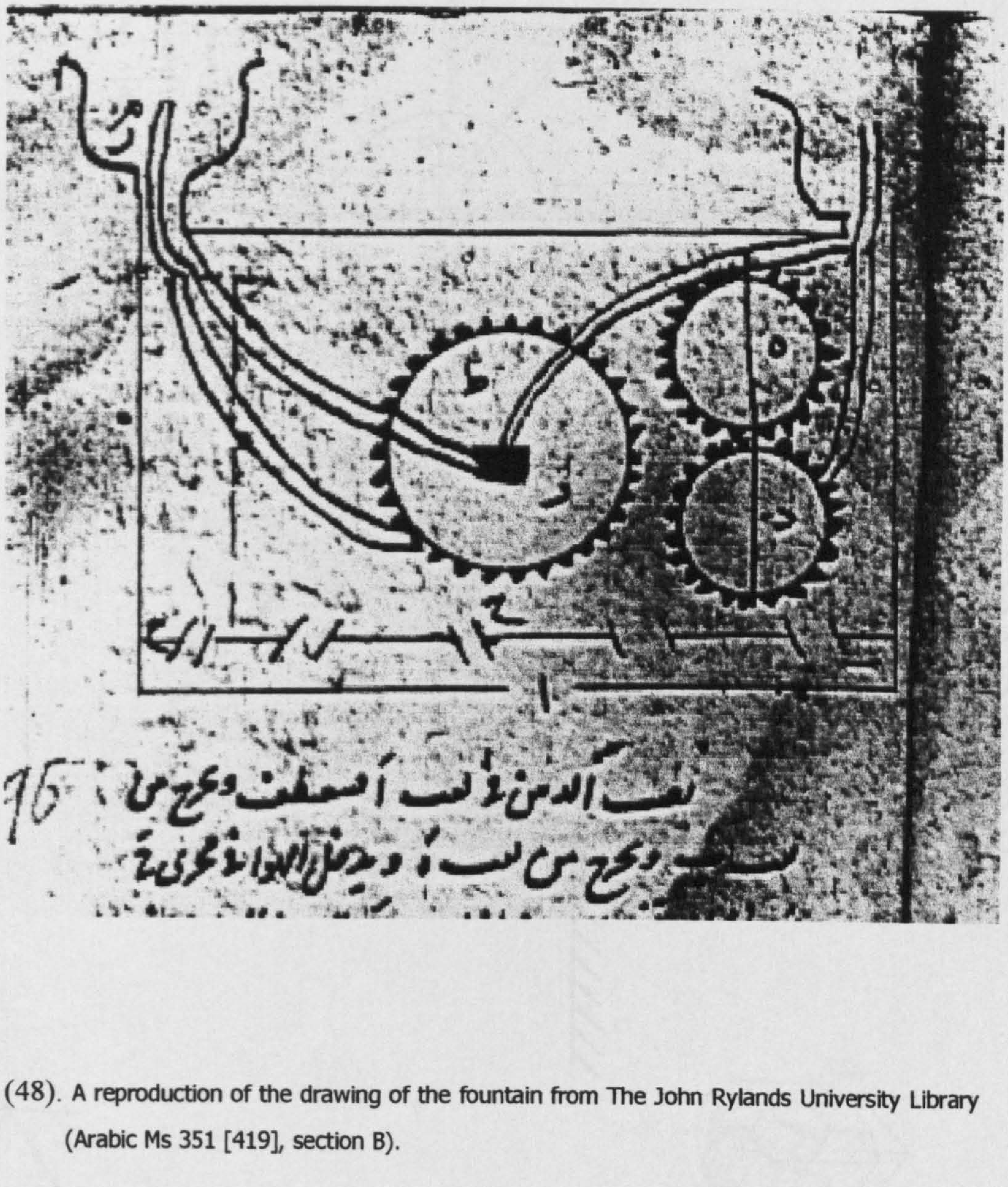
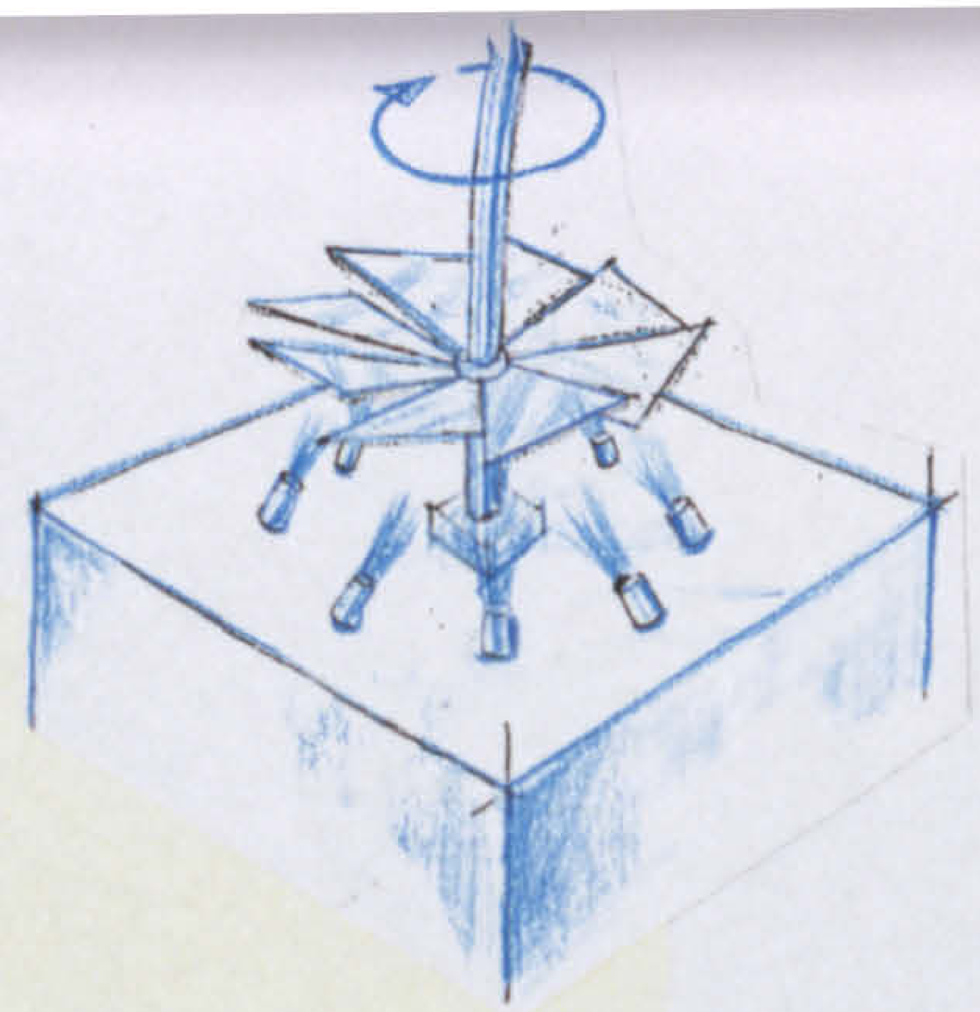
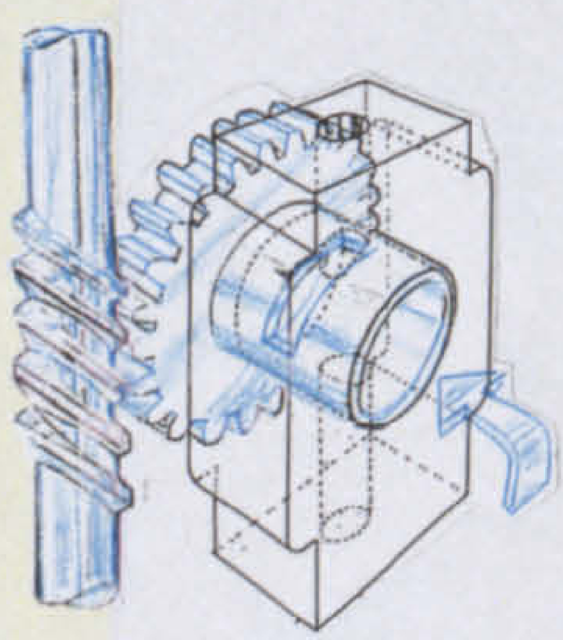


Figure (48). A reproduction of the drawing of the fountain from The John Rylands University Library (Arabic Ms 351 [419], section B).



The mechanism of this fountain is similar to the previous model, except it is fitted inside a cubic housing on top of which two fountain are erected.



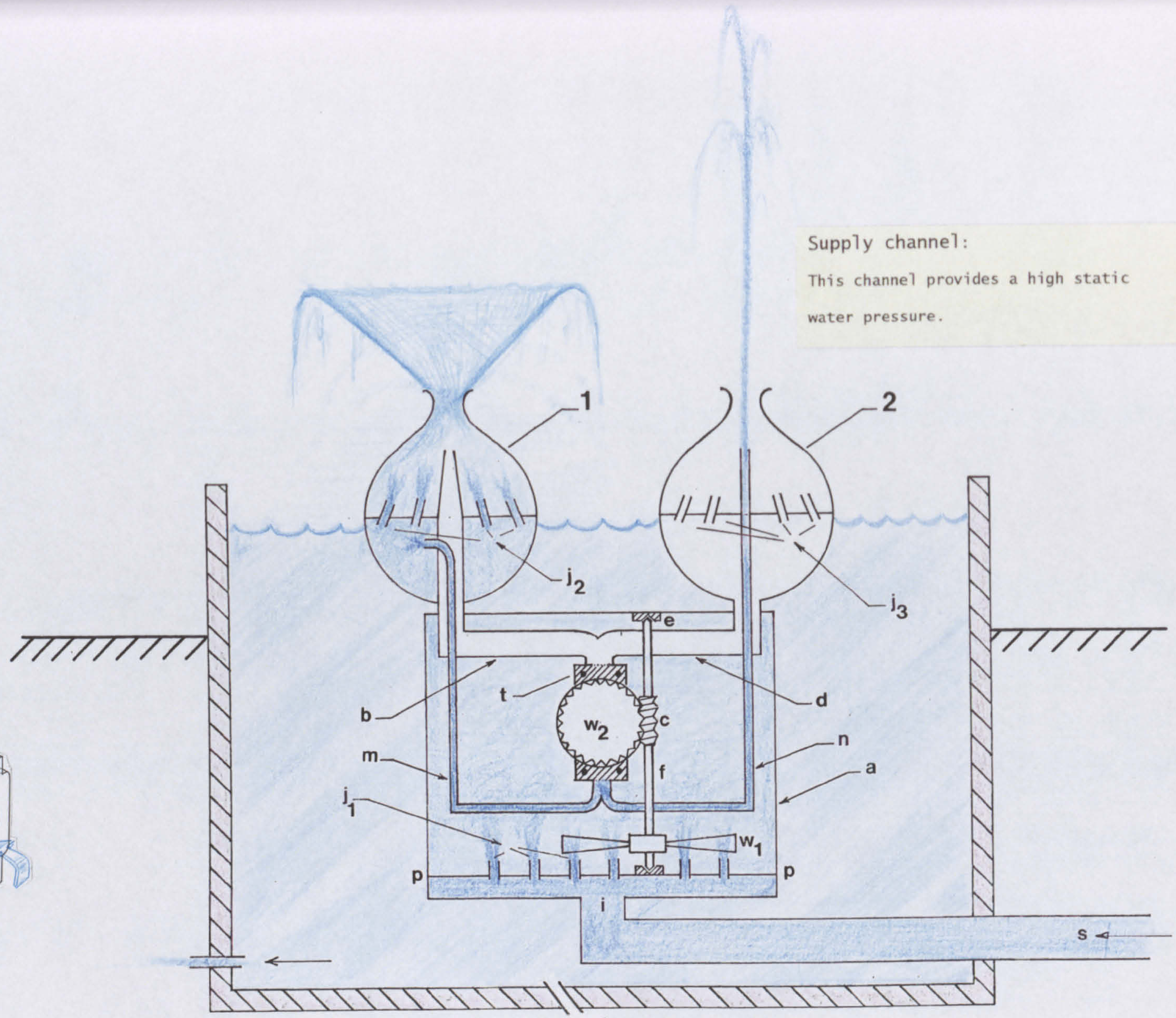


Figure 49: This modified drawing shows clearly the fountain's mechanism.

Experimentation of the Fountain-head

The following work describes a series of experiments which were designed and completed to test out the fountain-head, which was described by the Banu (sons of) Musa's work. Their designs dealt with different fountain-heads, but the one that was designed to produce the shape of a lily-of-the-valley is unique to them. Furthermore it is distinctively different from the fountain-heads which were designed by the other engineers, al-Jazari and Taqi al-Din. The basis of this current experimental work was drawn from the incomplete technical information given by Banu Musa; and also, from the unsatisfactory interpretation that Hill and al-Hassan have provided in their edited and annotated work of Banu Musa.

At this point it worth repeating the statement made by Hill who attempted to give an engineering o interpretation of how the shape of the lily-of-the-valley is created from that particular fountain-head, Hill write:

> "The design of the fountain-head is far from clear.... It seems plausible that the small pipes (h) were intended to increase the velocity and impart a swirling motion to the water. The design of the cone was presumably such that at discharge, the water was broken into separate streams each consisting of separate drops of water rather than a single jet thus imitating the shape of a lily-of-the-valley".[1]

Hill's assumption, however, according to the experimental work I have carried out seemed far from correct. Moreover, Hill has provided no explanation of how these small pipes create the swirling motion inside the fountain-head.

In the following work I have illustrated the construction of this fascinating fountain-head in which the mechanism of the small pipes is clearly explained. However, this experimental work is more practically and artistically orientated rather than theoretically based.

[1] Banu Musa (1). *The Book of Ingenious Devices*. Edited by Hill, Donald. p. 197.

Therefore the experiments are restricted to a number of variables and constants related to the size, angle, direction, etc. of the fountain-head components, which are set to examine the shape of the water emitted from that particular fountain-head. In order to obtain definite measurement of these emissions I have a grid board right behind the fountain-head, each square in this grid is 1x1 inch. Despite the fact that I was constrained by limits in my working space, which was not prepared for such experiments, the twenty-nine experiments have produced some fascinating results. These results can be watched on the attached video recordings, to which the reader may refer, for clearer visual presentation.

- **Experimental settings**

1. Constants:
   - A conical fountain-head made of plastic. See figure 50 for technical detail.
   - Pressure of the water that is pumped into the fountain-head from a water-pump (3200 gallons per hour), which is controlled by a valve. The rough estimate of the water-pressure used in all experiments is less than 25% of the full potential of the pump.
   - The distance between the small pipe/jets and the wall of the fountain-head.
   - Size of the jets.
2. variables:
   - The orifice of fountain-head used is 16mm, 18mm and 13mm.
   - The angle of the jets erected on the base plate are 19.5°, 90°, 22.5° and 10°.
   - The positioning of the jet on the base plate, which are upwards and downwards.
   - The number of the jets inside the fountain-head.

There will be technical details given for each experiment on the setting of the variable elements including a brief analysis on the results.

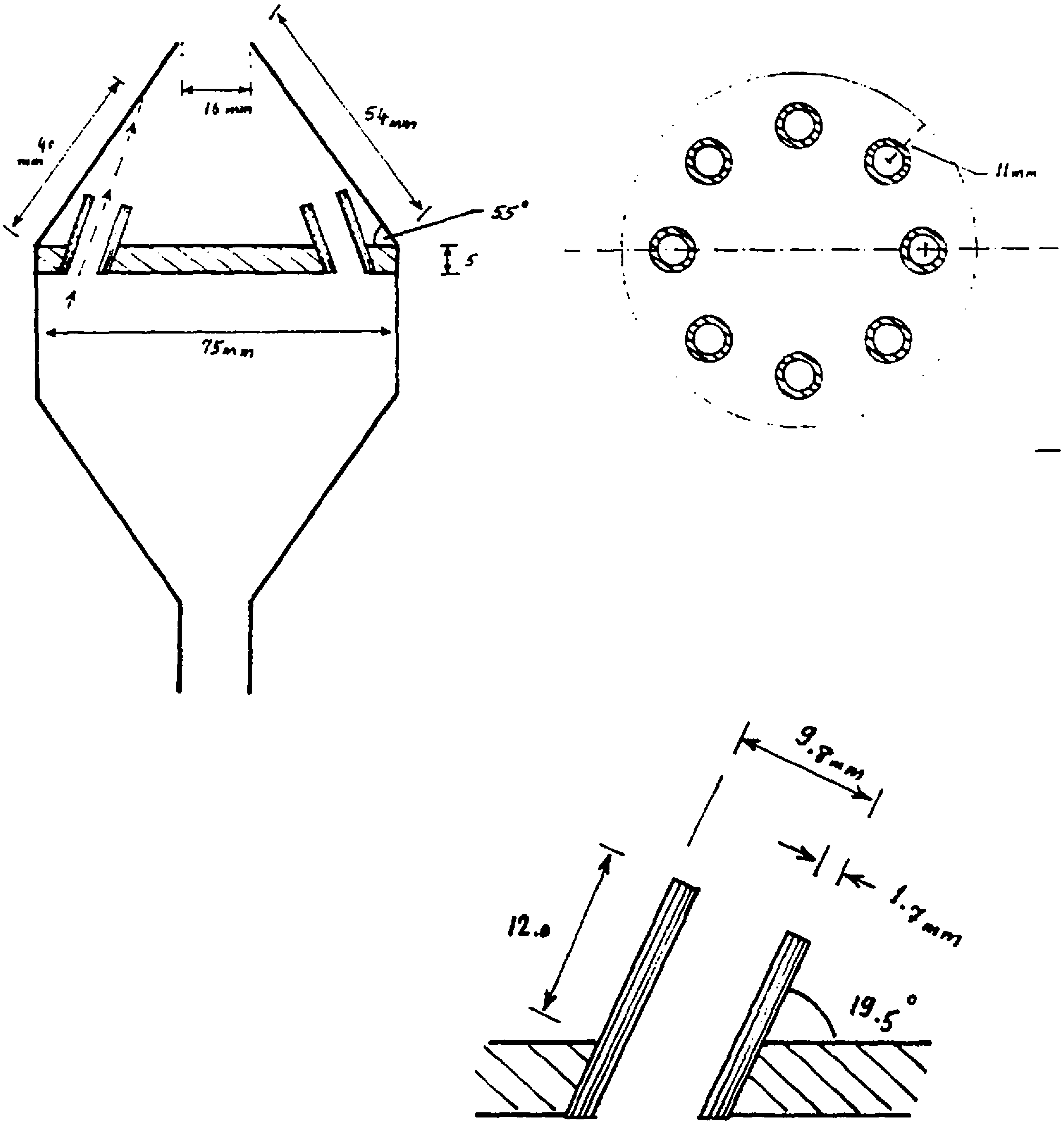


Figure (50)

Techincal detail of the foountain-head.

▫ Experiment 1.

In this experiment, I have tried to examine the construction of the fountain-head as it was described by Banu Musa, and represented by Hill and al-Hassan. The description refers to numerous inclined jets (pipes) that are positioned close to the inner rim of the plate, which makes the base of the conic fountain-head. The water flow from them hit the cone's wall at points close to the orifice. The technical detail of this fountain-head is showed in figure 50.

Variables:

- Eight inclined jets at a 19.5° angle and upwards positioning.
- 16mm orifice.

Results:

- A very low vertical jet, see figure 51. The simple explanation of this result is that these jets seemed to cancel each other, and this is why the single jet became an inevitable result.

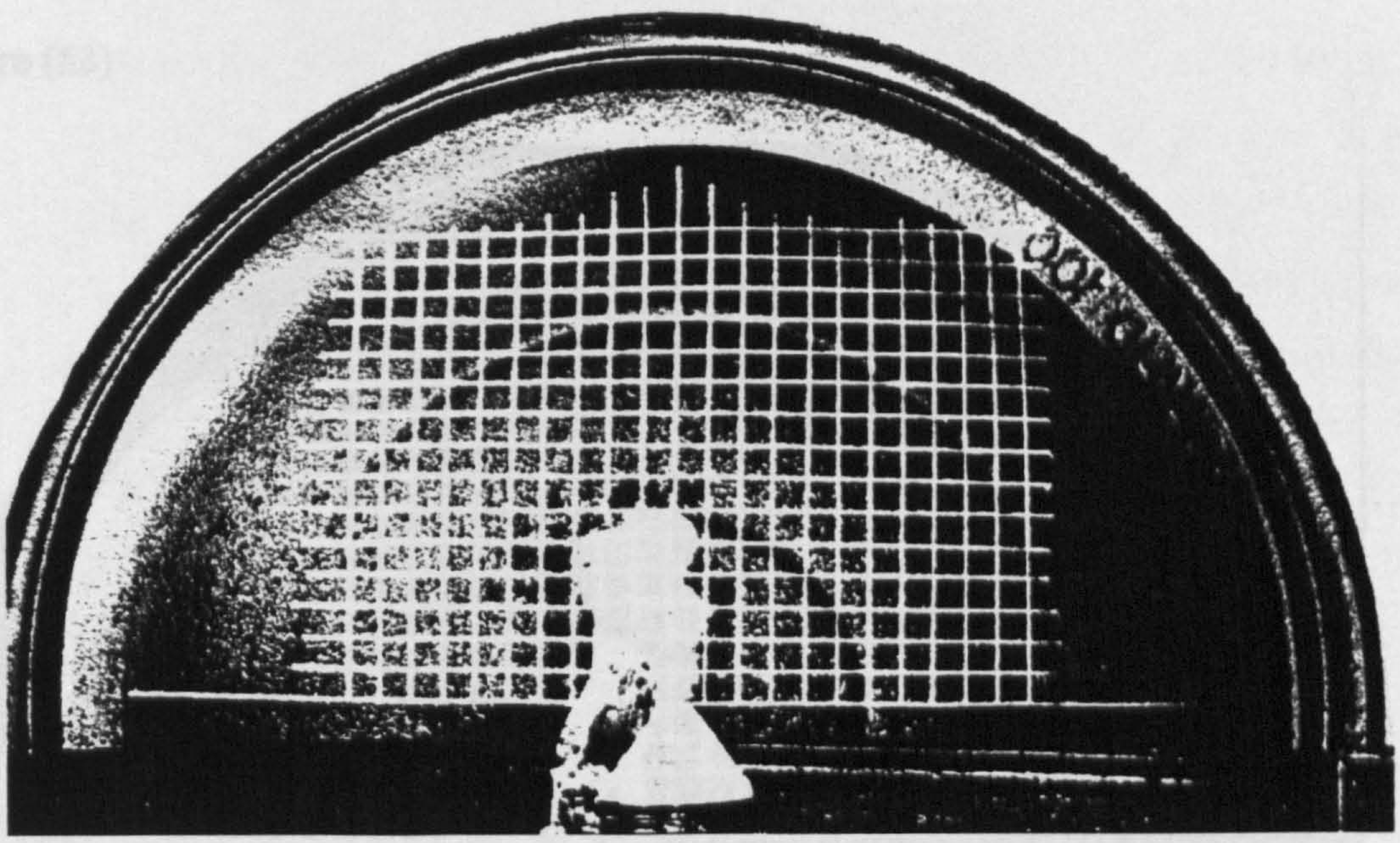


Figure (51)

Experiment 2

The setting of the jets in this experiment is arranged differently as shown in figure 52.

Variables:

- Eight jets at 90° angle.
- 16mm orifice.

Results:

As shown in figure 53 a better vertical jet is produced than in the previous experiment, this could be because the different introduction of the jet within the cone.

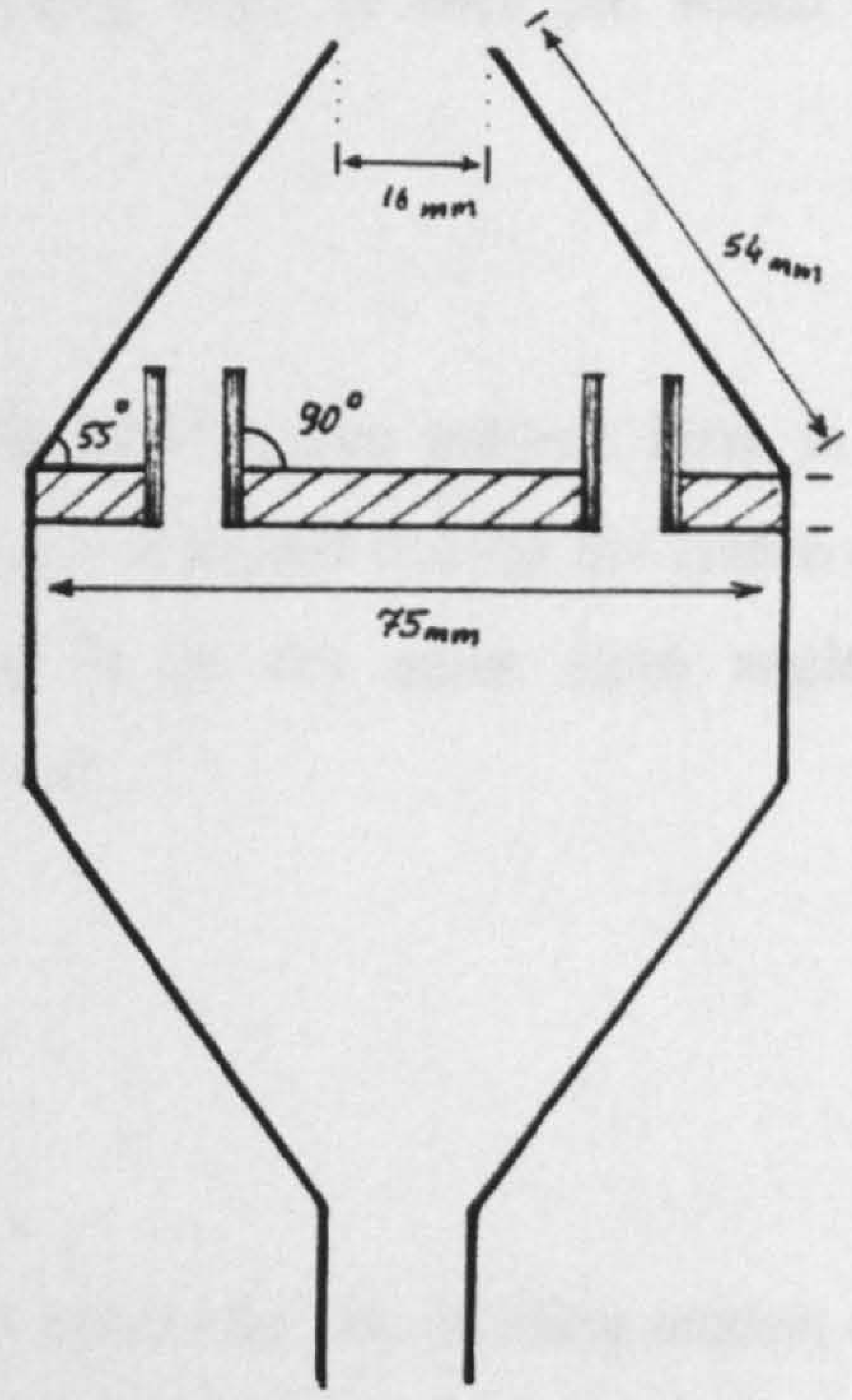
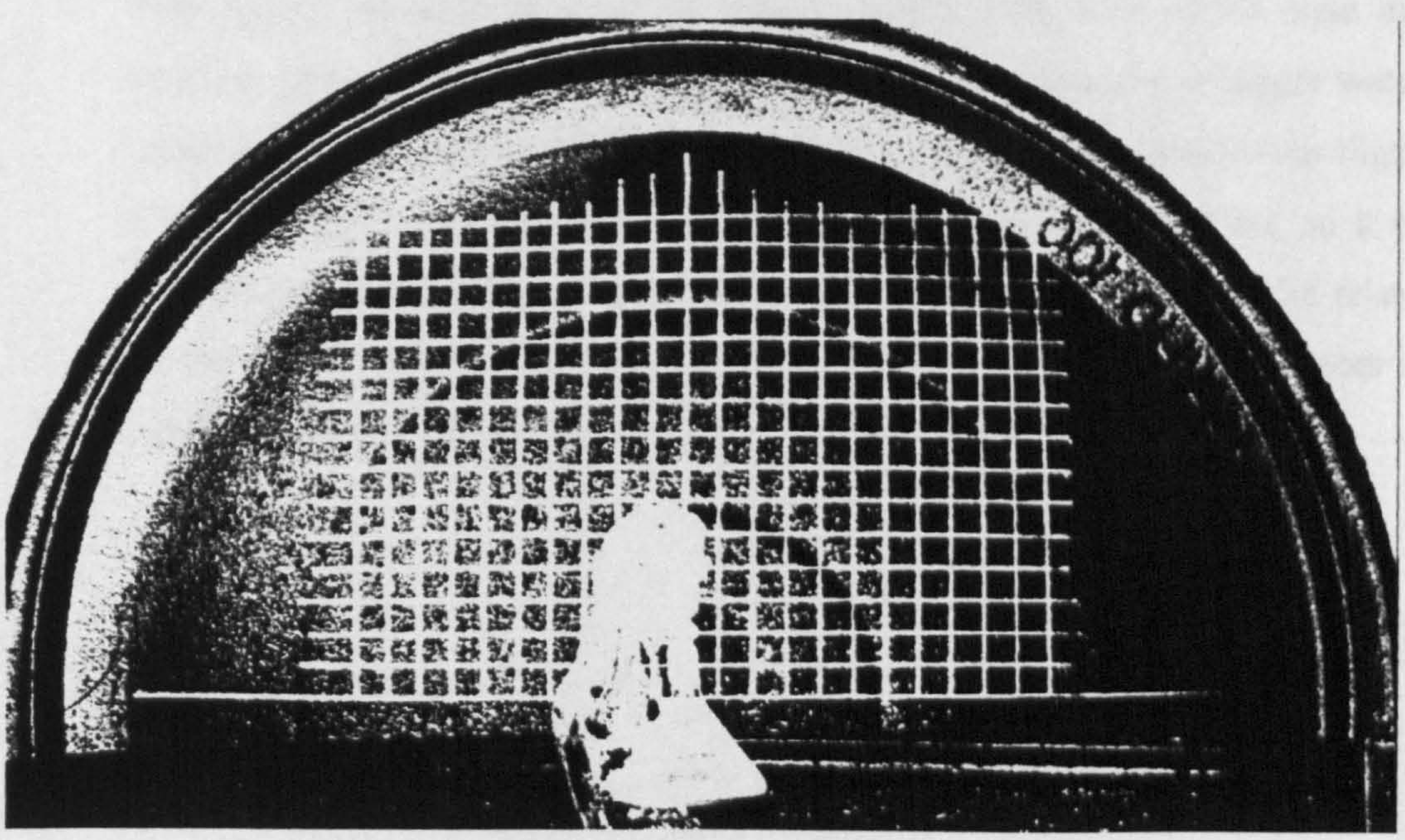


Figure (52)

Figure (53)



▫ Experiment 3

It was realised from the first experiment that the inclined jets did not serve the purpose of producing an emission of a lily-of-the-valley as they were set in one direction. Therefore, I have added another inclining angle to each jet, which is explained in the setting of the fountain-head.

Variables:

- Eight jets are erected at the angle, 19.5° in two settings: First, in a radial setting, which means each jet is angled toward the centre of the plate. Second, this setting is at the same time angled circumferencetialy (See Figure 54).
- Upwards positioning of the jets.
- 16mm orifice.

Results:

There was a very radical change in the water behaviour; the swirling motion of the water inside the cone created by the double-angled jets produced an upside-down cone, which in a way resembled the shape of a lily-of-the-valley. This setting allowed the water to flow over the inner wall of the cone in a swirling motion that is continued outside the cone, producing a bigger water-cone which later breaks up to streams of drops, almost horizontally (see Figure 55). The water-cone, or lily-of-the-valley, produced was turbulent, so it did not retain a fixed height. The initial analysis of this turbulence may be related to the water pressure and the surface tension, which are crucial factors by which the height and breaking-up of the water-cone are determined.

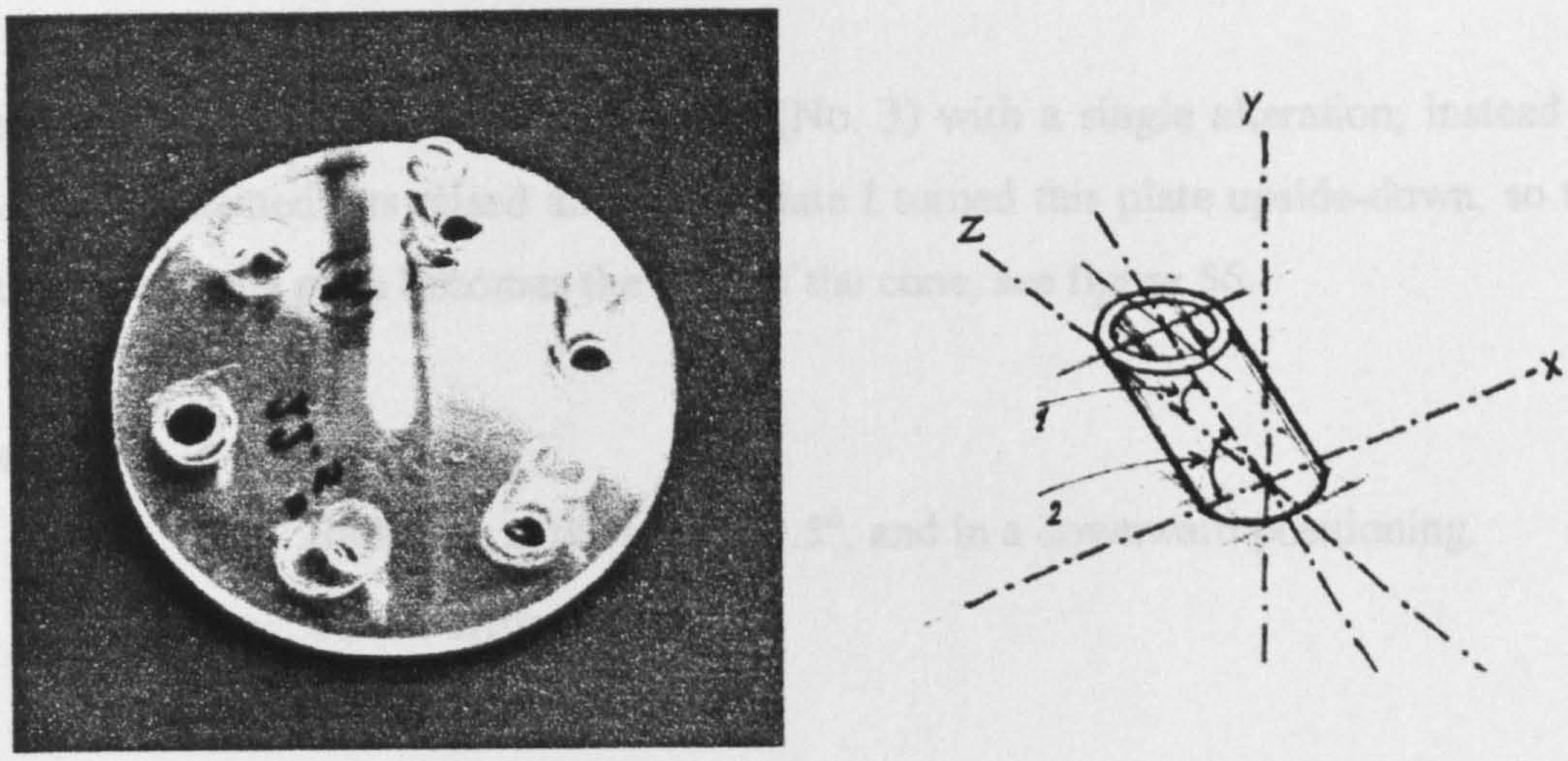


Figure (54)

An example of nozzle arrangement
in the order 3, 4, 5 ,6 7, 8, 10, 12.

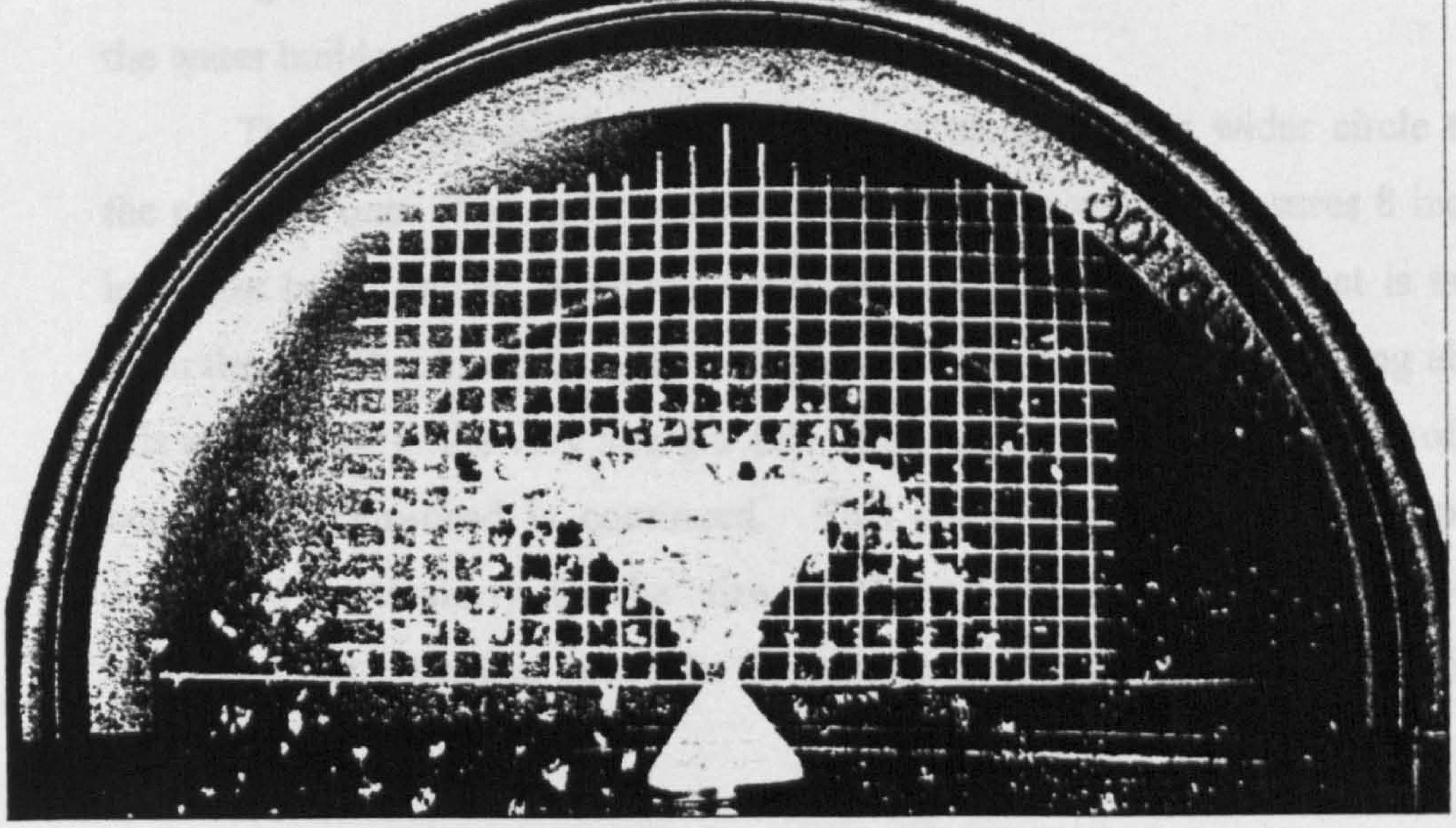


Figure (55)

▫ Experiment 4

Here I repeated the previous experiment (No. 3) with a single alteration; instead of having the inclined jets raised above the plate I turned this plate upside-down, so the flat surface of the plate becomes the base of the cone, see figure 56.

Variables:

- Eight jets at the angle 19.5°, and in a downward positioning.
- 16mm orifice.

Results:

Surprisingly, the result was a turbulence-free emission; in other words the water-cone maintained a firm shape and constant height, see figure 57. The obvious explanation of this result, I have assumed, is that in the previous experiment the nozzles were inhibiting the smooth swirling motion of the water, and this is why some sort of turbulence occurred inside the fountain-head. Figure 58 shows the water-cone created and how the swirling motion of the water builds up the wall of the water-cone.

The breaking-up of the water-cone stretches over a wider circle than the previous one. The water-cone, or the lily-of-the-valley measures 8 inches in height by 12 inches in width, approximately. This measurement is taken from the grid that located on the background. The most intriguing thing about this water-cone is the very straight side of its wall, in which the outline of the conical fountain-head is continued. This continuity of the conic shape is connected particularly to the size of the orifice. Also the cylinder-like whirlpool that is created inside the fountainhead is interesting, see figure 59.

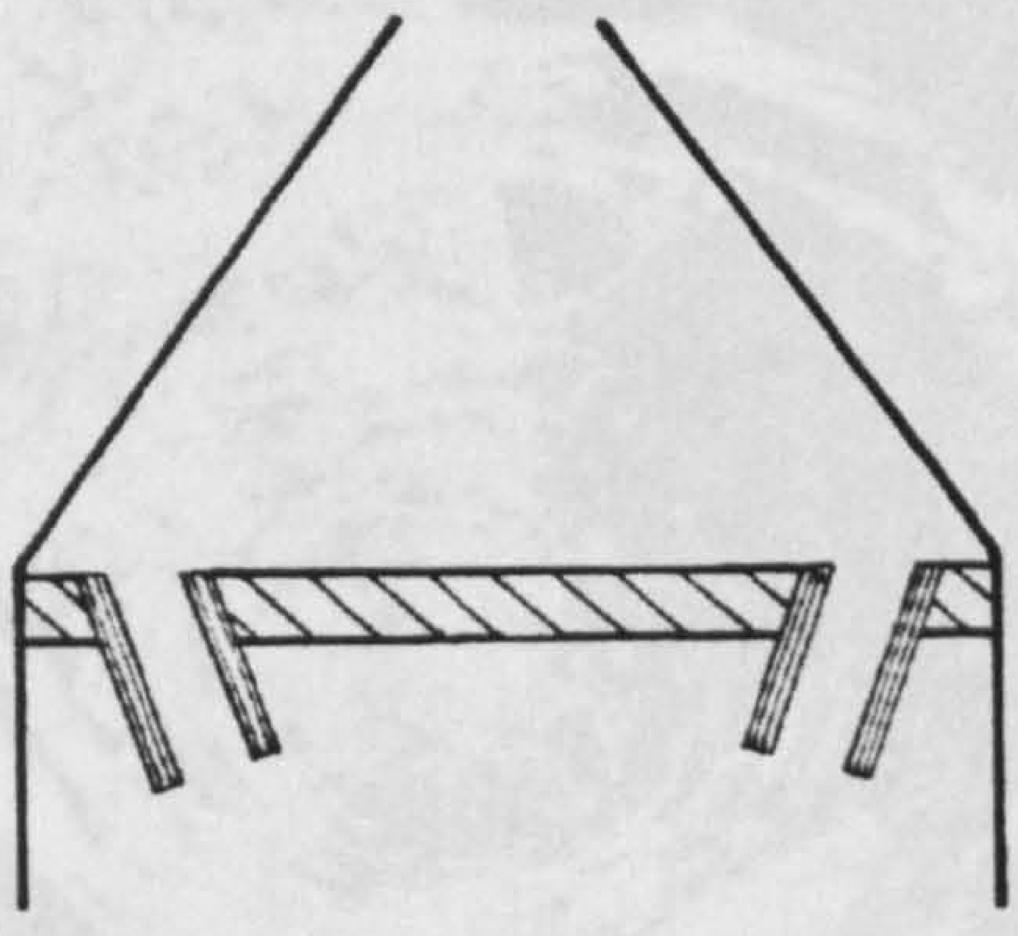


Figure (56)

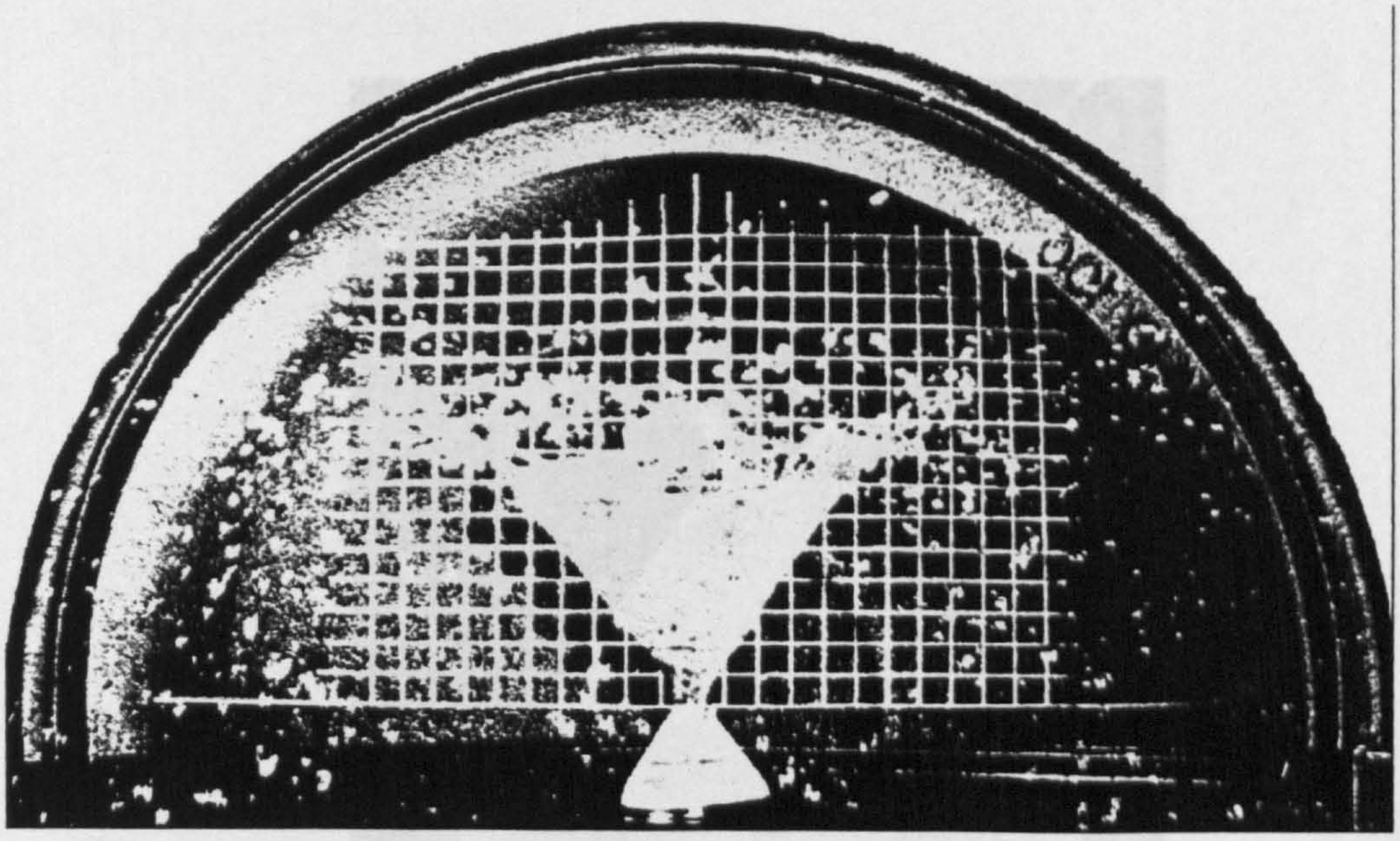


Figure (57)

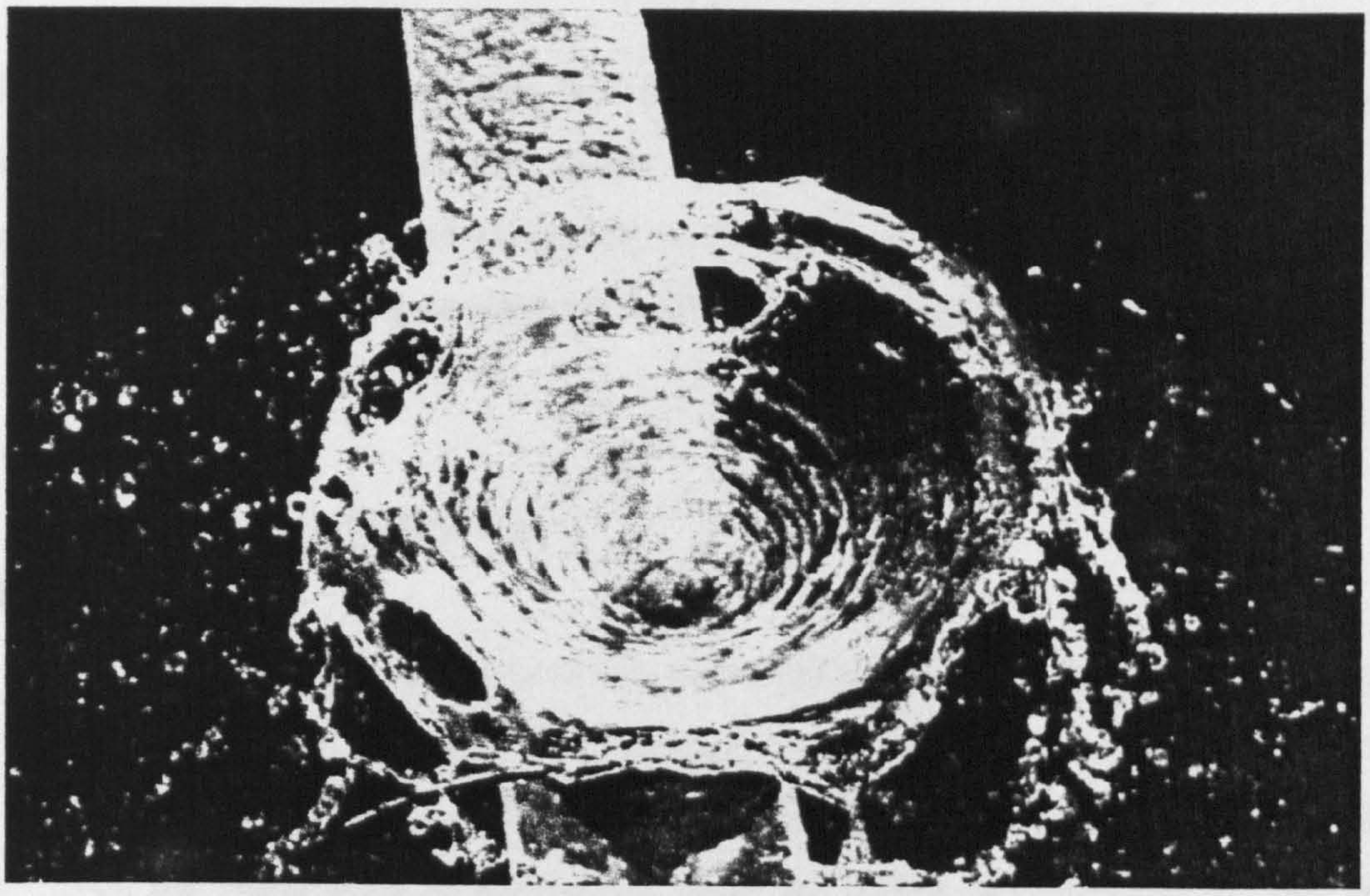


Figure (58)

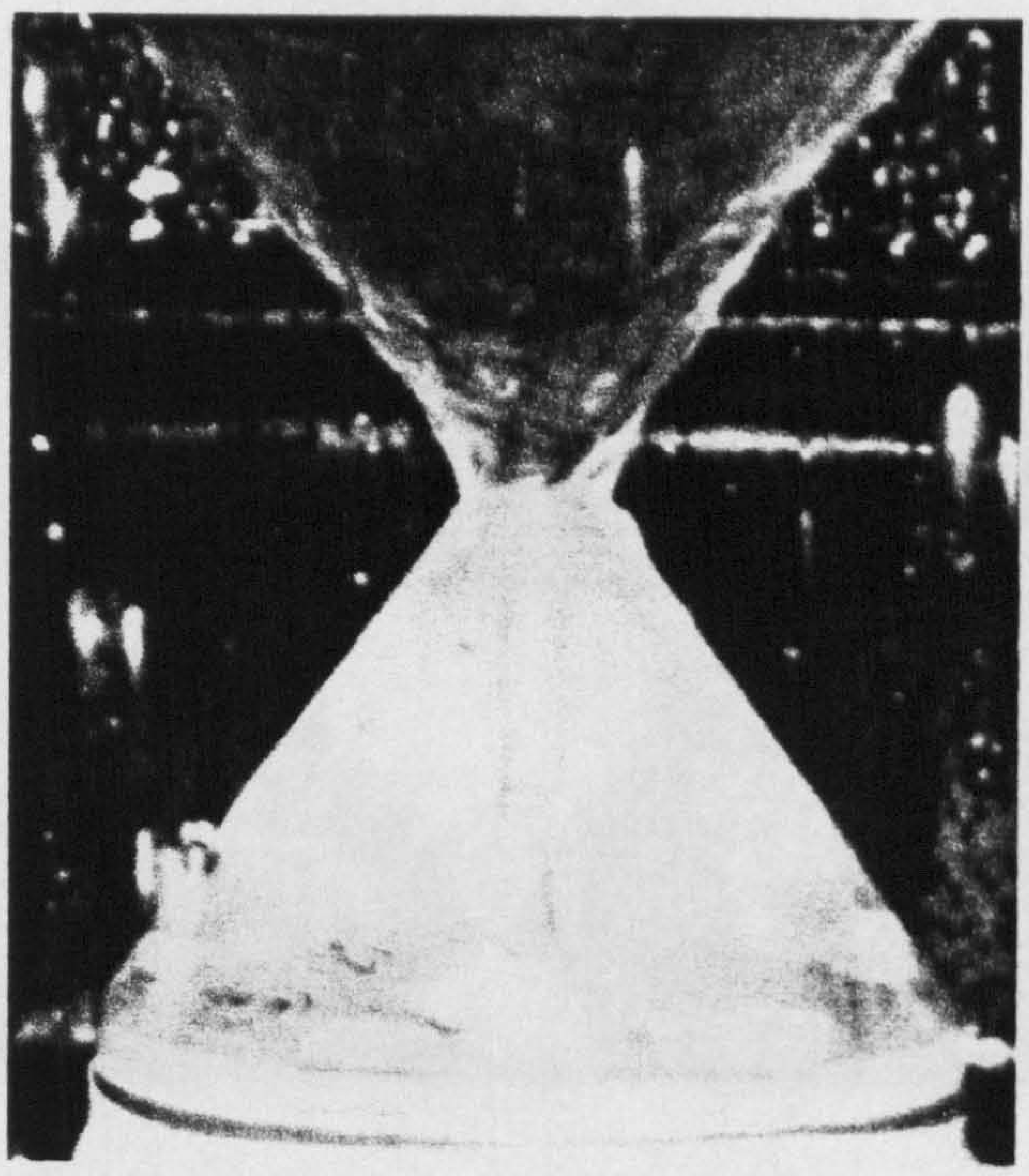


Figure (59)

Experiment 5

The previous experiment showed that the positioning of the nozzles below the base plate, leaving the floor of the conic fountain-head completely flat, provided a significantly improved result compared to the result of experiment three. Therefore this setting will be a constant element in all following experiments.

Variables:

- Six jets at the angle 19.5°.

Results:

The water in this experiment has, to a certain extent, maintained its behaviour as in the previous experiment, although the velocity in the nozzles is high, that is due to the increased pressure below the base plate. The height and the width of the water-cone is almost the same as in the previous result. The only difference is the speed of the breaking-up at the top of the water-cone, which seemed to be a little faster than in the previous experiment, which is why the falling-circle of the water-drops is slightly wider, approximately 100-centimetres (see figure 60).

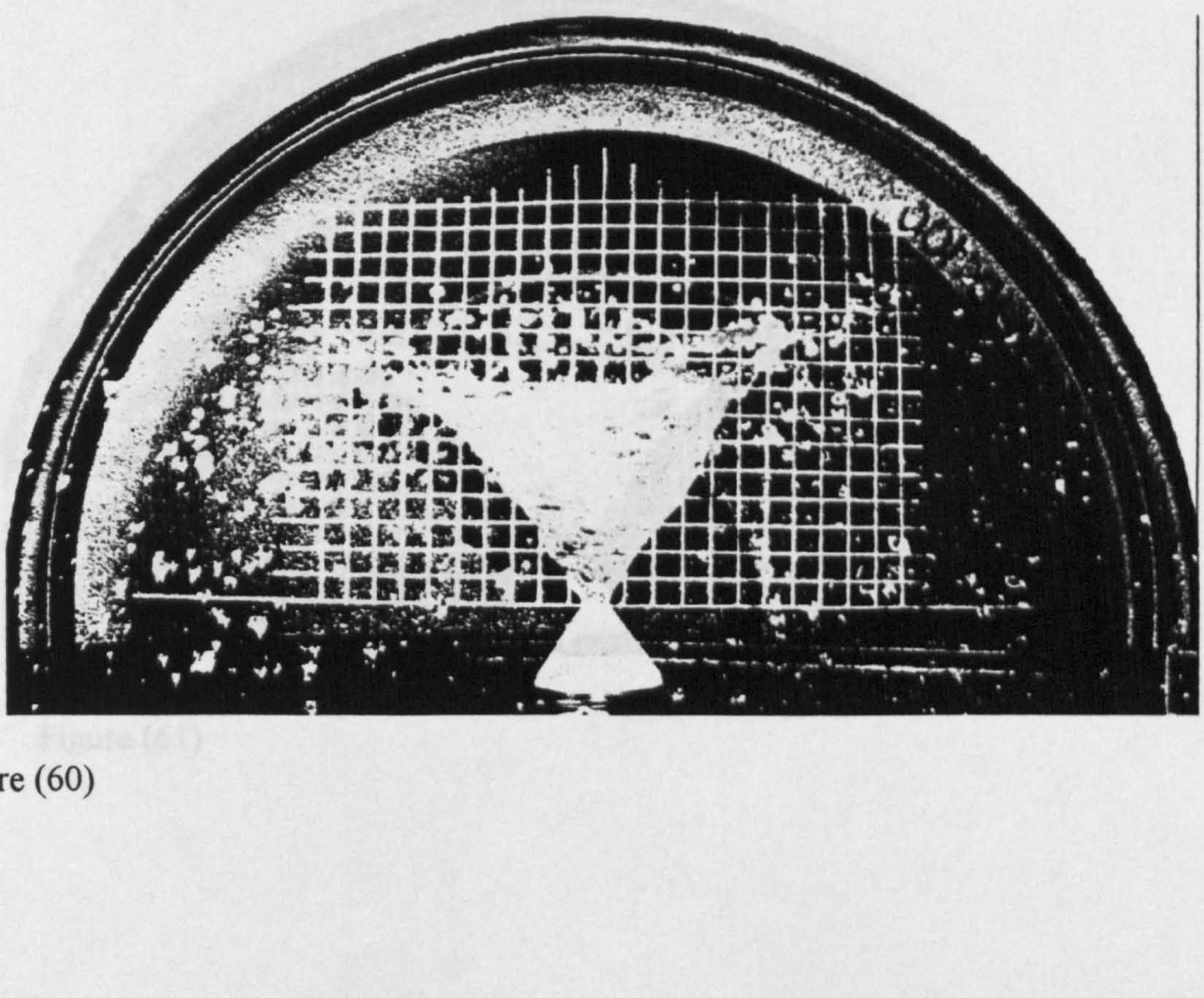


Figure (60)

Experiment 6

Variables:

- Four jets at the angle 19.5°.

Results:

The result showed a significant change in terms of the shape produced. The water-cone is slightly higher and wider than in the previous experiment, but it breaks into streams of drops that were thrown into the air, in continuous lines. These water-drops then fall down in a much wider circle. The behaviour of the water in this experiment can be interpreted as follows; by decreasing the jet's number, a high pressure is created below the base plate, therefore higher velocity in the nozzles and more swirl inside the fountain-head. This consequently has produced a water-cone with a rather thinner wall. The surface tension on the water-cone's wall seems to be constant, and effectively resulted in the breaking up of the thinner wall into smaller drops which are thrown to a higher level and falling in a wider circle. See figure 61.

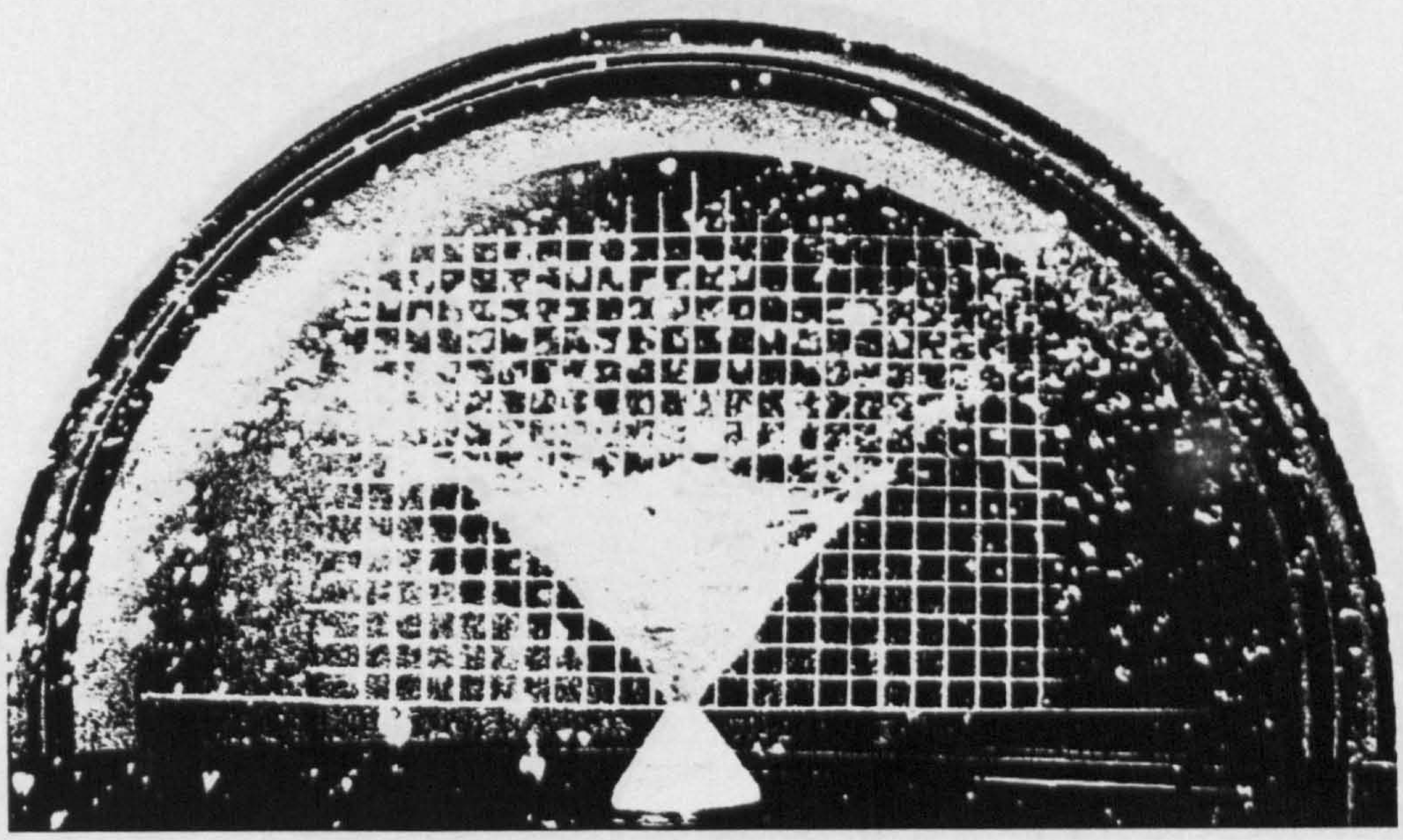


Figure (61)

Experiment 7

Variables:

- Three jets at the angle 19.5°.

Results:

There is no significant difference in results when compared to the previous experiment. In figure 62, the emission appeared to have the same characteristics as those of experiment 6, although the water-cone seemed to be a bit higher and wider. This is because the velocity in the nozzles and the swirling motion inside the fountain-head have increased slightly to that of experiment No. 6, which means less volume of water flowed inside the fountain-head, and consequently a thinner wall of the water-cone was created. The breaking-up of the cone, on the other hand, was into smaller and faster drops which were thrown into the air at a slightly wider angle.

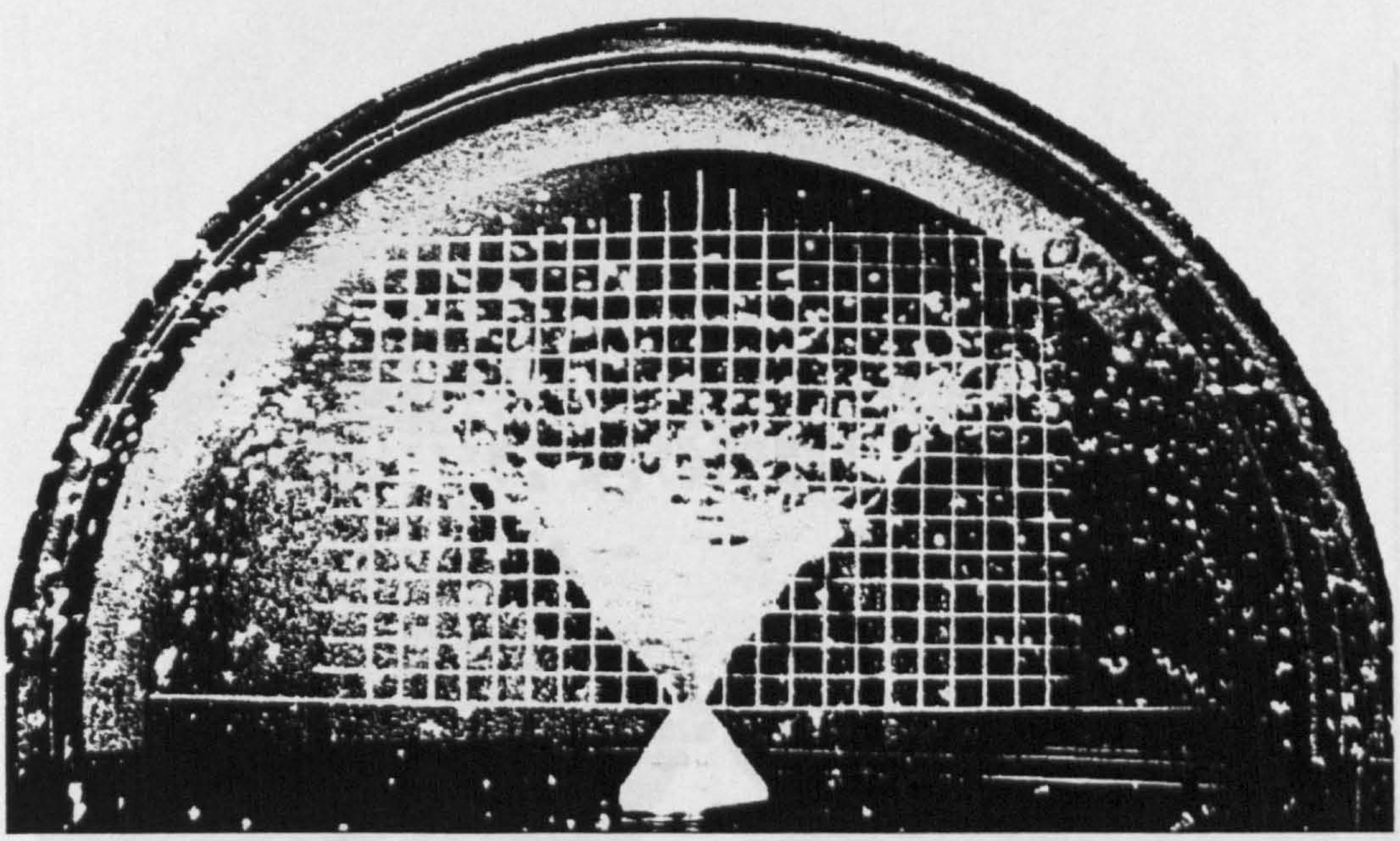


Figure (62)

❑ Experiment 8

In this experiment, and the following seven, I have altered the angle and the number of the jets.

Variable:

- Twelve jets at the angle 22.5°.

Results:

This experiment produced a water-cone approximately 8-inches in height and 12-inches in width. The change in both dimensions is related to the higher volume of the water deposited into the conical fountain-head, which means more water-pressure is created inside the fountain-head. The breaking-up of the cone, on the other hand, appeared to be into bigger drops that fall within a closer circle. This result can be justified by the more volume of water inside the fountain-head, therefore a thicker wall water-cone is created, and consequently the water-cone is lower in height. See figure 63.

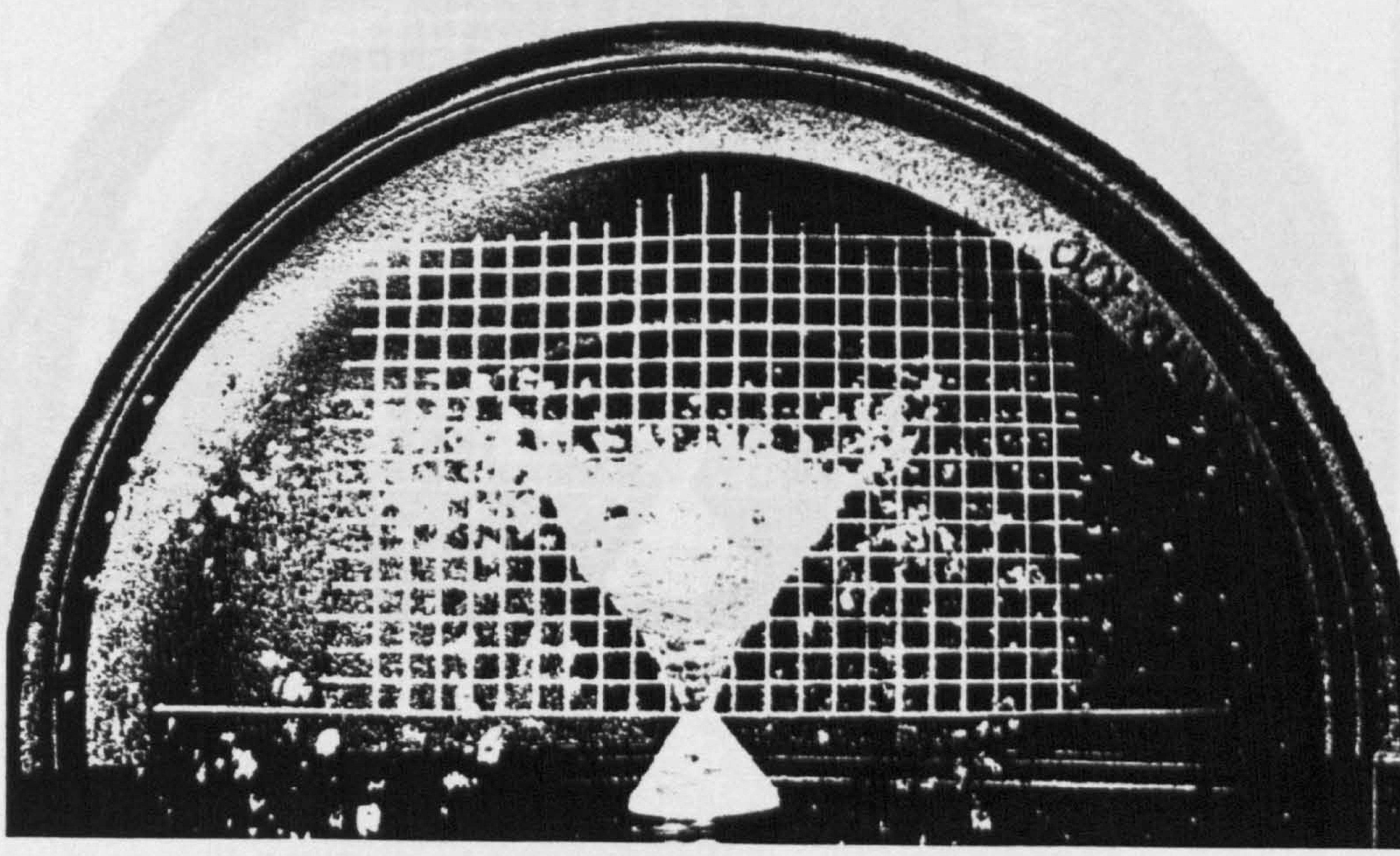


Figure (63)

Experiment 9

Variable:

- Ten jets at the angle 22.5°.

Results:

This experiment produced very similar results to the previous experiment, although the velocity in the nozzles was increased slightly; see figure 64. The slight reduction of the water volume inside the fountain-head and more flow out the fountain-head did not create a significant difference in comparison to experiment eight.

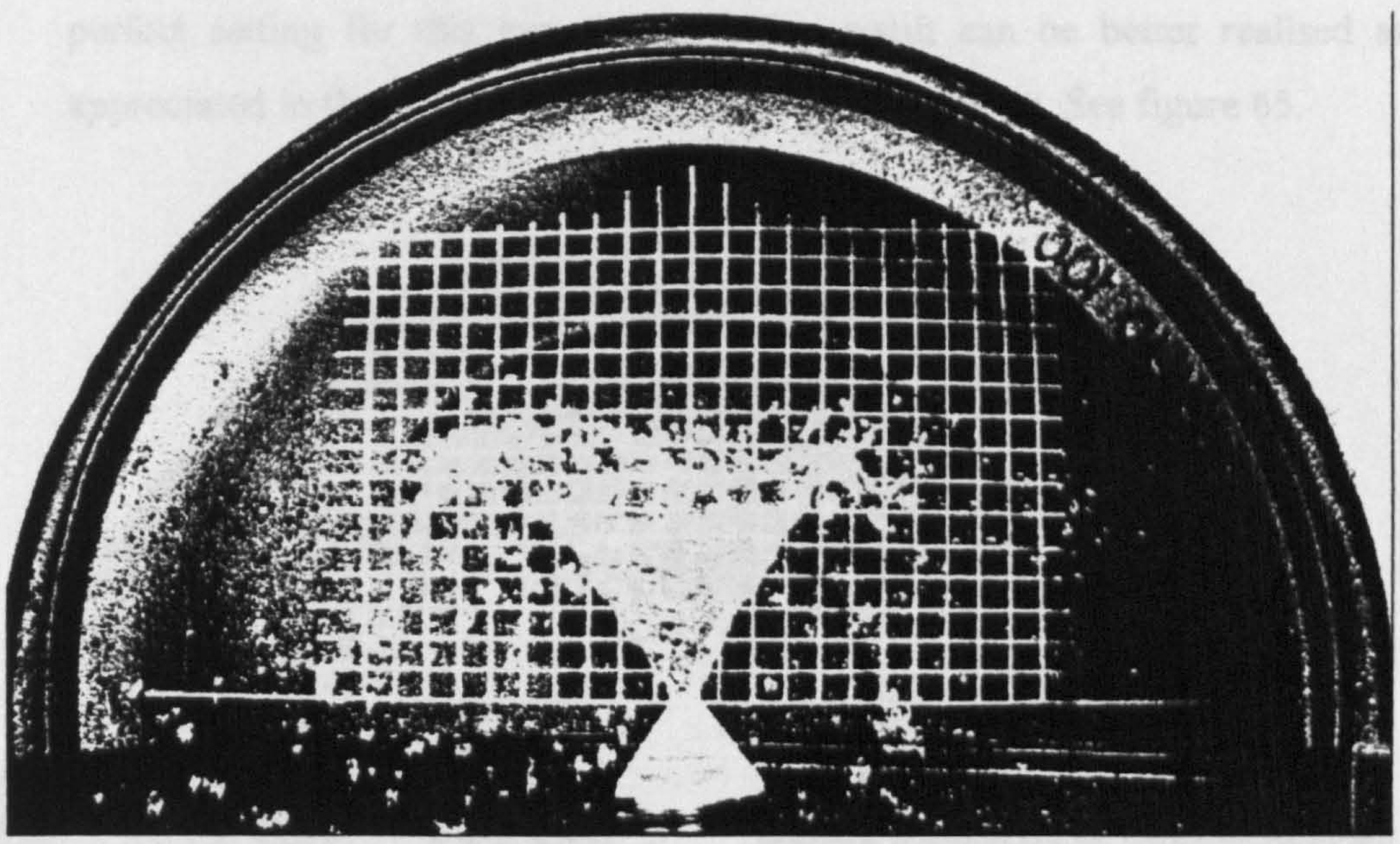


Figure (64)

❑ <u>Experiment 10</u>

Variable:

- Eight jets at the angle 22.5°.

Results:

This experiment produced an elegant water-cone that curves out at its top, breaking into medium sized drops that fall in a circle of 3-4 foot in diameter, approximately. The water-cone, however, is wider and higher because of the increased water-pressure inside the fountain-head; it measures approximately 16 inches in width and 10 inches in height. The surface tension on the water-cone's wall seemed to be in perfect balance with the other elements, which resulted in the distinctly thin, smooth and glass-like wall of the water-cone. The delicate relationships, however, between the number and the angle of the jet, and the size, angle and the orifice of the conic fountain-head, made a perfect setting for this experiment. This result can be better realised and appreciated in the video recording attached to this thesis. See figure 65.

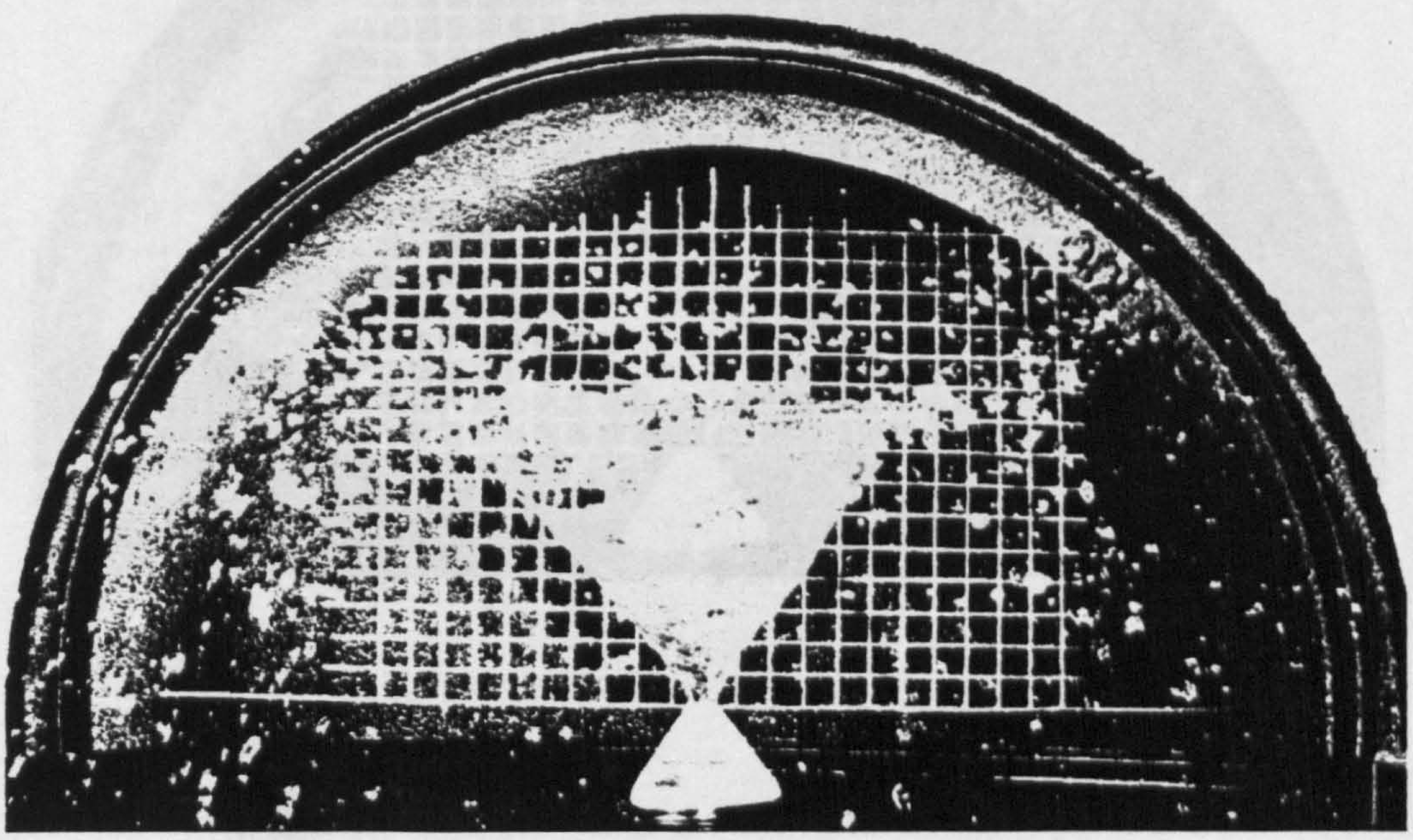


Figure (65)

Experiment 11

Variables:

- Seven jets at the angle 22.5°.

Results:

This experiment created a similar water-cone to that of the previous experiment, although it did not have that smooth and glossy surface. The falling circle of the water-drops is slightly wider, due to the increase of the water swirl velocity. Figure 66.

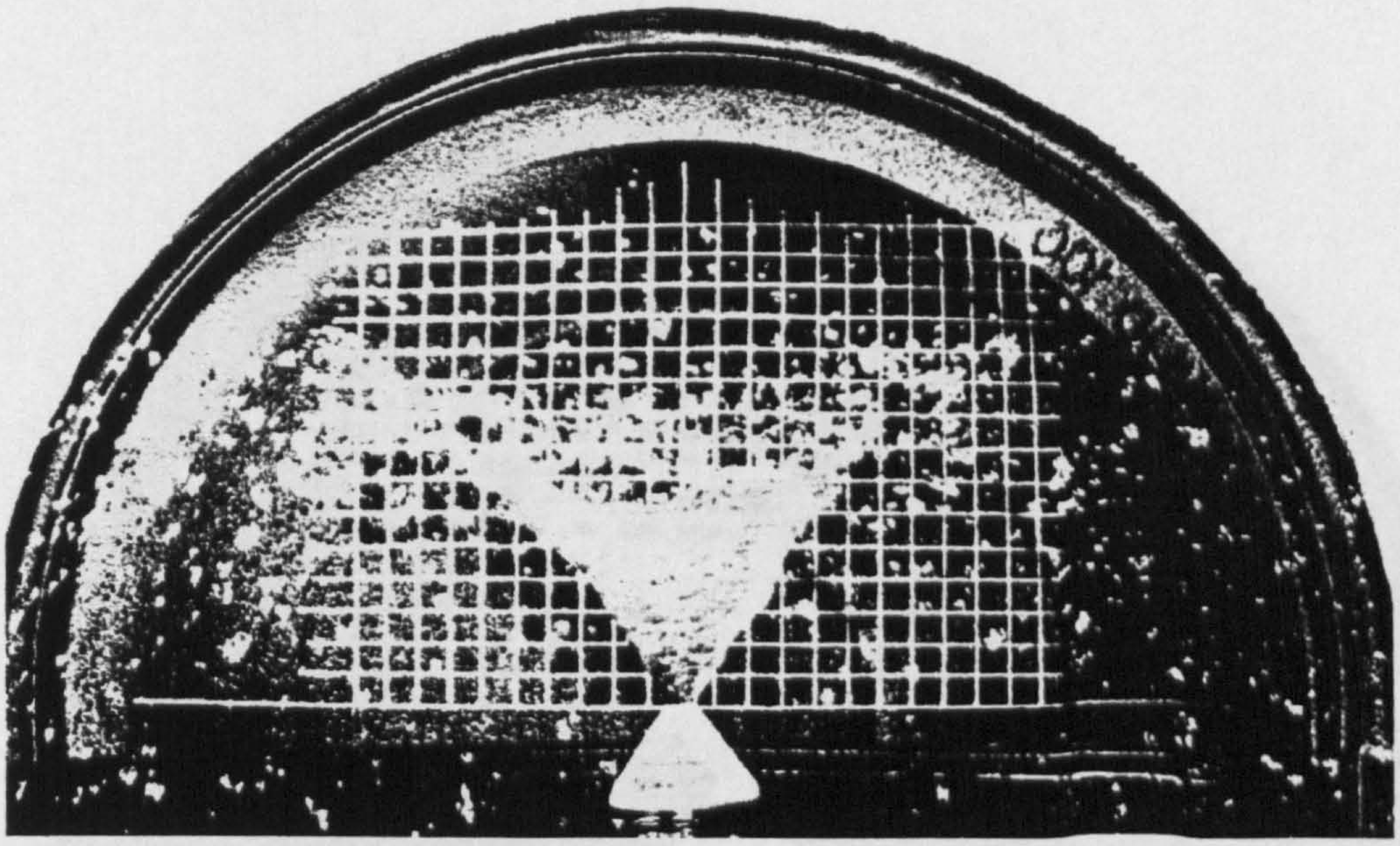


Figure (66)

Experiment 12

Variables:

- Six jet at the angle 22.5°.

Results:

By decreasing the number of the jets to six, the result showed an increase in the effect of the surface tension on the wall of the water-cone, which created a wider falling circle of the water-drops. Figure 67 shows the direction of water-drops as the breaking up of the water cone occurs. The result in this experiment shows little difference in comparison to experiment 5 in which the same number of jets was used, although they were angled differently.

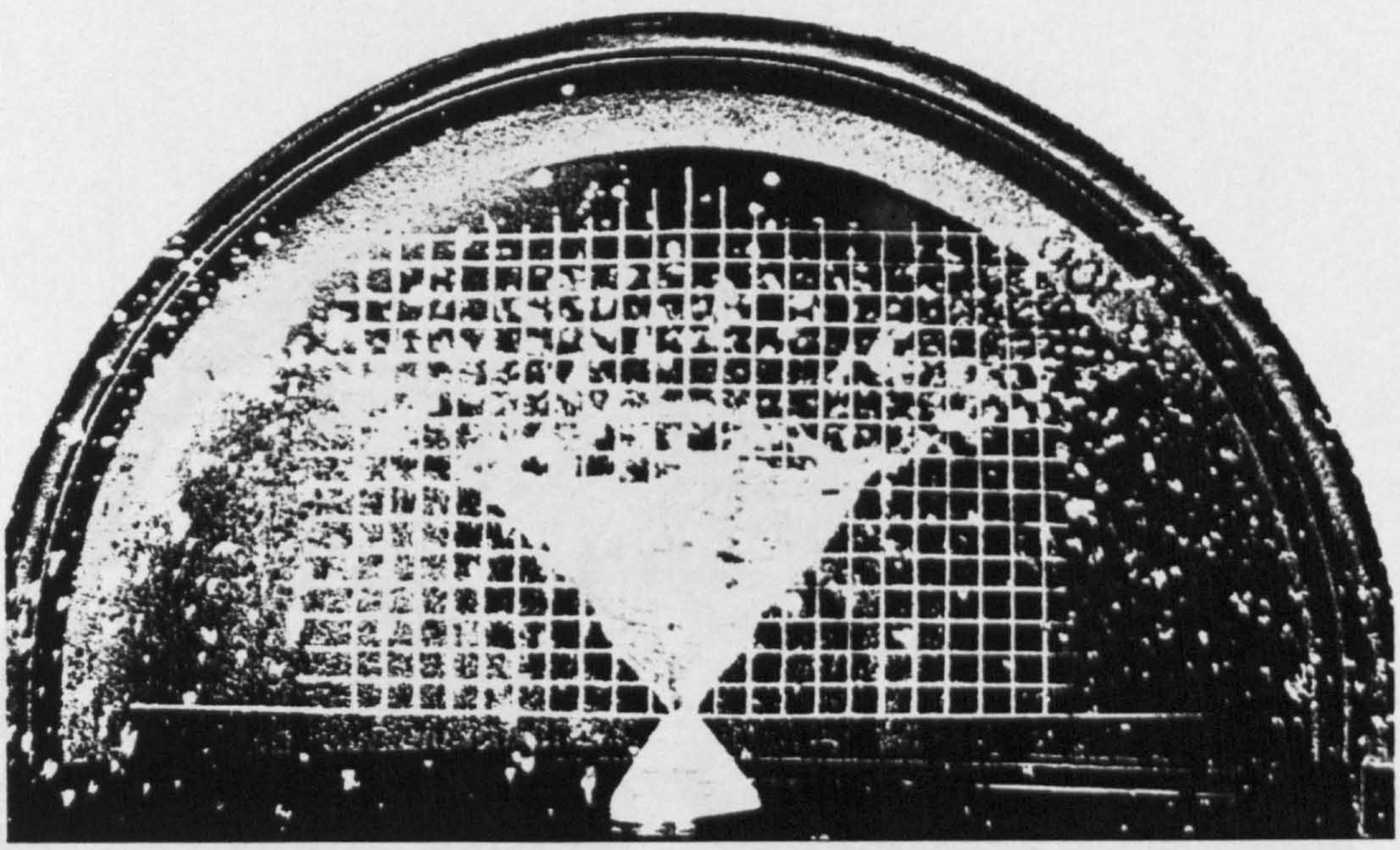


Figure (67)

❑ Experiment 13

Variables:

- Five jet at the angle 22.5°.

Results:

The increased water swirl created by the five jets in this experiment produced a thin walled water-cone that broke up into small water-drops, which scatter in a much wider circle, 200 centimetres in diameter, approximately. Because the effect of the surface tension is significantly increased thinner wall, the breaking up point of the water-cone's wall tended to be lower than in the previous experiments. Figure 68 shows the direction of the water-drops as the water-cone starts to break up.

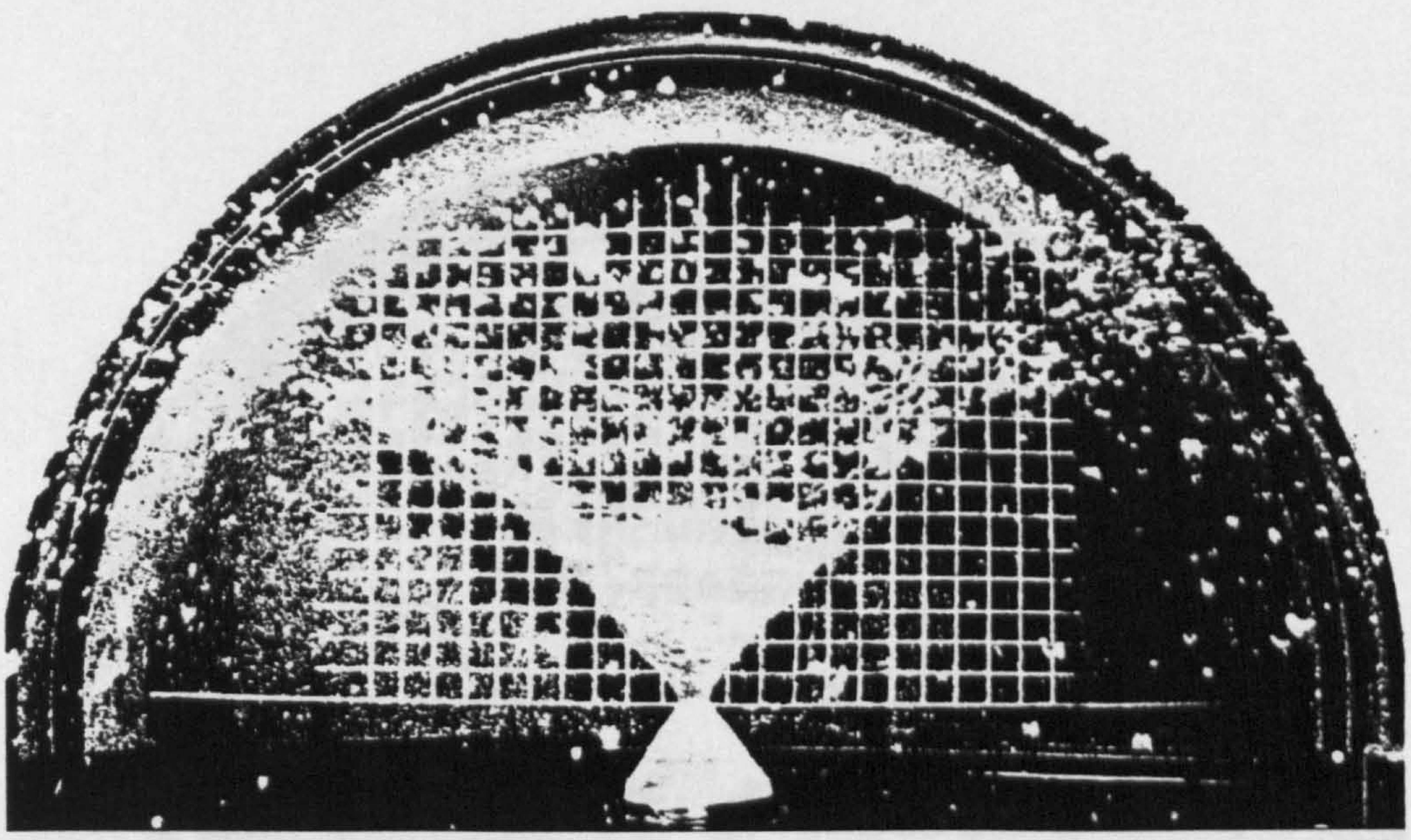


Figure (68)

Experiment 14

Variables:

- Four jets at the angle 22.5°.

Results:

The water velocity in this experiment is even higher than in the previous one. The four jets used have lowered the volume of water passing through the jet and consequently the water swirl and the effect of the surface tension have increased. The speed of the breaking up of the water-cone has become greater which caused the water-drops to fly higher into the air, and fall in a wider circle. As in the previous experiment, the breaking up point on the wall is even lower. However, the outline of the water-cone, surprisingly, appears much straighter. See figure 69.

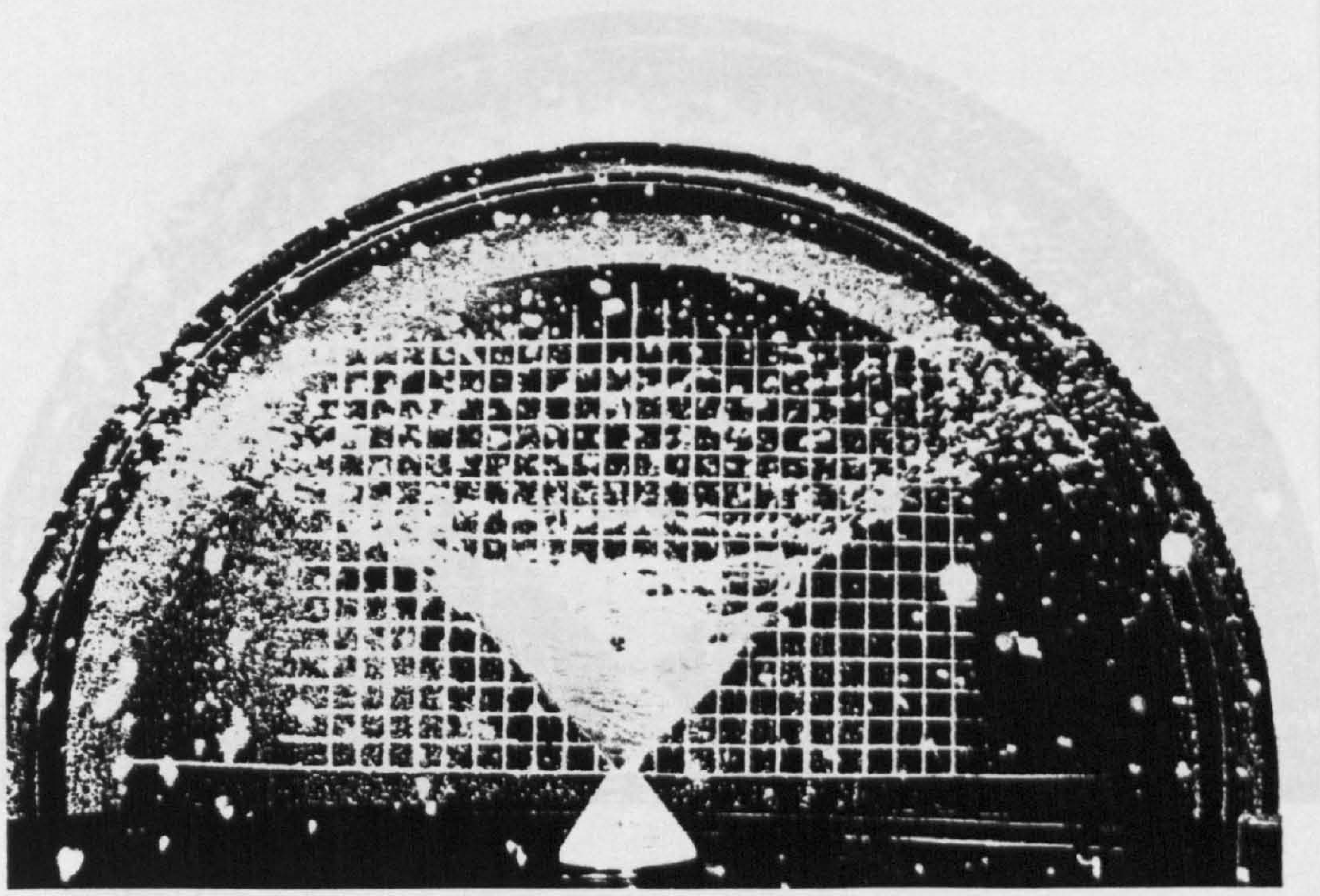


Figure (69)

▫ Experiment 15

Variables:

- Three jets at the angle 22.5°.

Results:

The speed of the breaking up of the water-cone's wall is very high in comparison to the three previous experiments. The three jets used have increased the water-pressure below the cone significantly, therefore higher velocity in each nozzle. This produced a much thinner wall and a greater falling-circle for the water-drops, see figure 70. However, the water-cone maintained its straight outline.

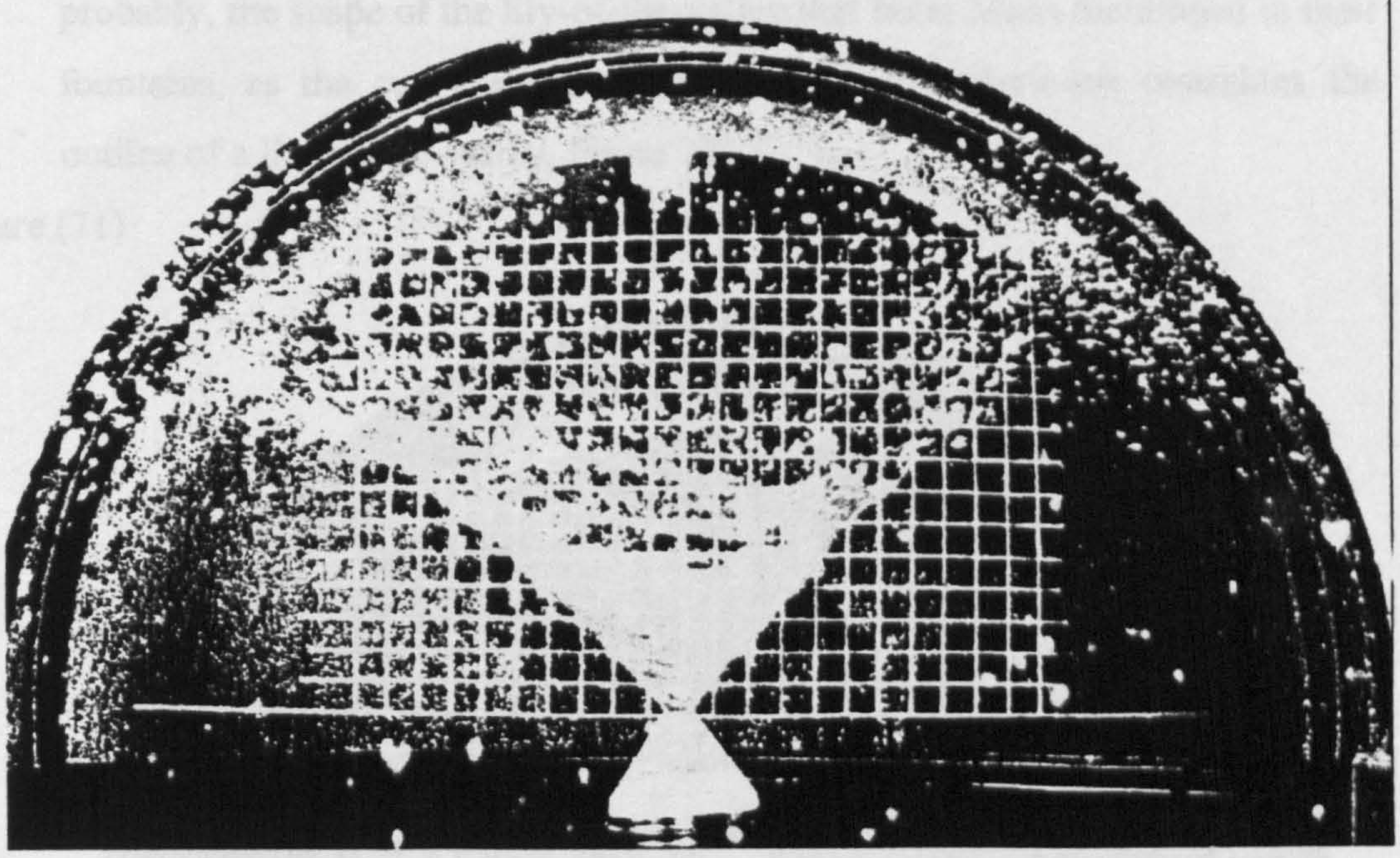


Figure (70)

Experiment 16

Since experiments 4 and 10, in particular, appeared to me to have the most balanced relationships between the all components that create the fountain-head, I tried to examine the effect of the size of the orifice on the emissions. Therefore, in this experiment, and also the next five, I have altered the diameter of the fountain-head's orifice.

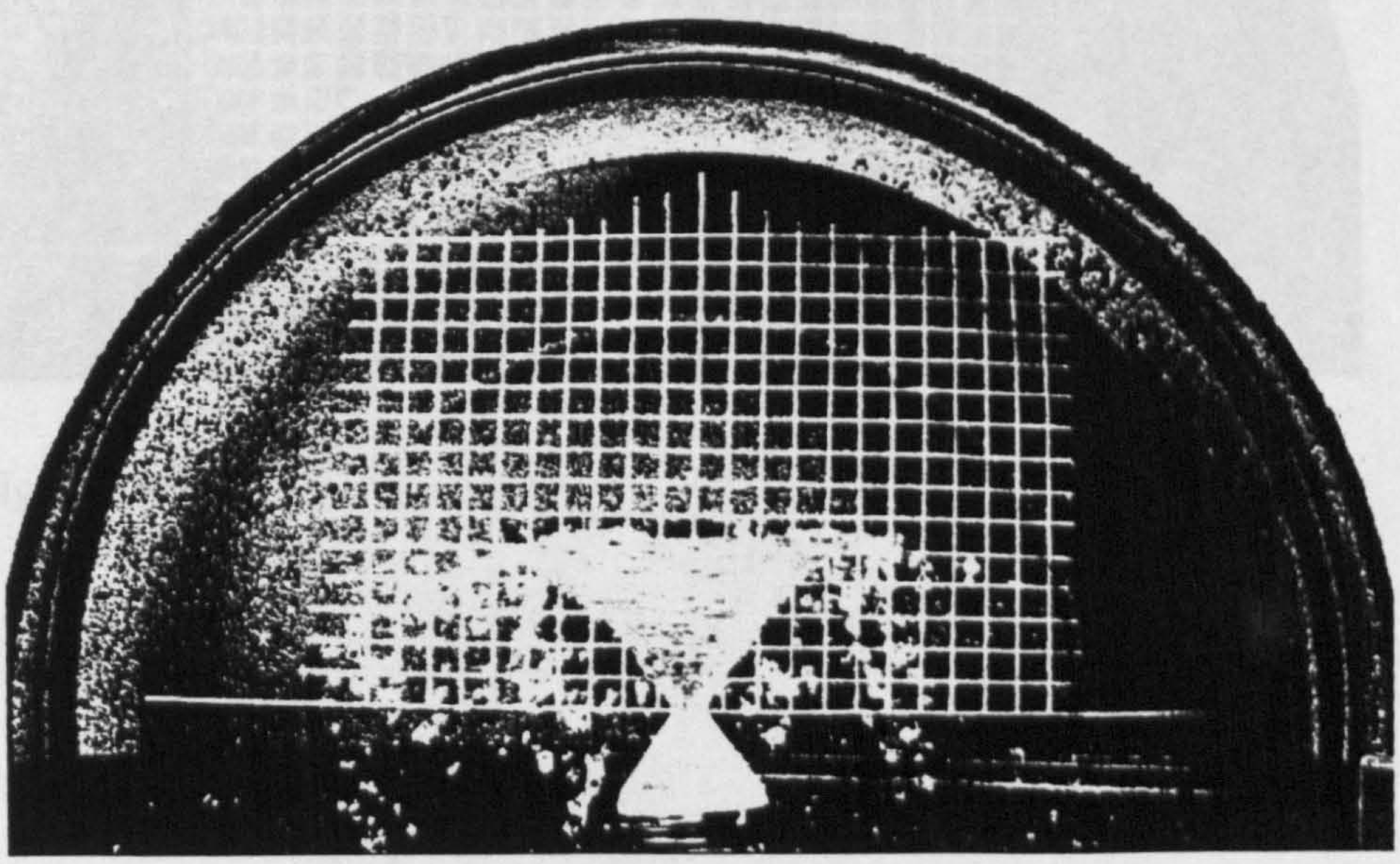
Variables:

- Eight jets at an angle of 19.5°.
- An 18mm diameter orifice.

Results:

In comparison to the result of experiment 4, the water-cone produced in this experiment is distinctly different. By widening the orifice, the water-pressure at the orifice became lower than in experiment 4. This, of course, resulted in a thicker wall and a lower height water-cone. The water-cone here tends to curve out horizontally before starting to break up. This shape is, most probably, the shape of the lily-of-the-valley that Banu Musa mentioned in their fountains, as the curvy shape of the top of the water-cone resembles the outline of a lily-of-the-valley, figure 71.

Figure (71)



❑ Experiment 17

Variables:

- Six jets at the angle of 19.5°.
- 18mm orifice.

Results:

The result of this experiment in comparison to experiment 5, which has the same setting except the diameter of the orifice, is significantly different. The widening of the orifice created the same pattern as the previous experiment; thicker wall, lower height and curvy top with large breaking up water-drops, see figure 72. As in experiment 16 the result is governed by three factors; the balance of gravity, surface tension and centrifugal action.

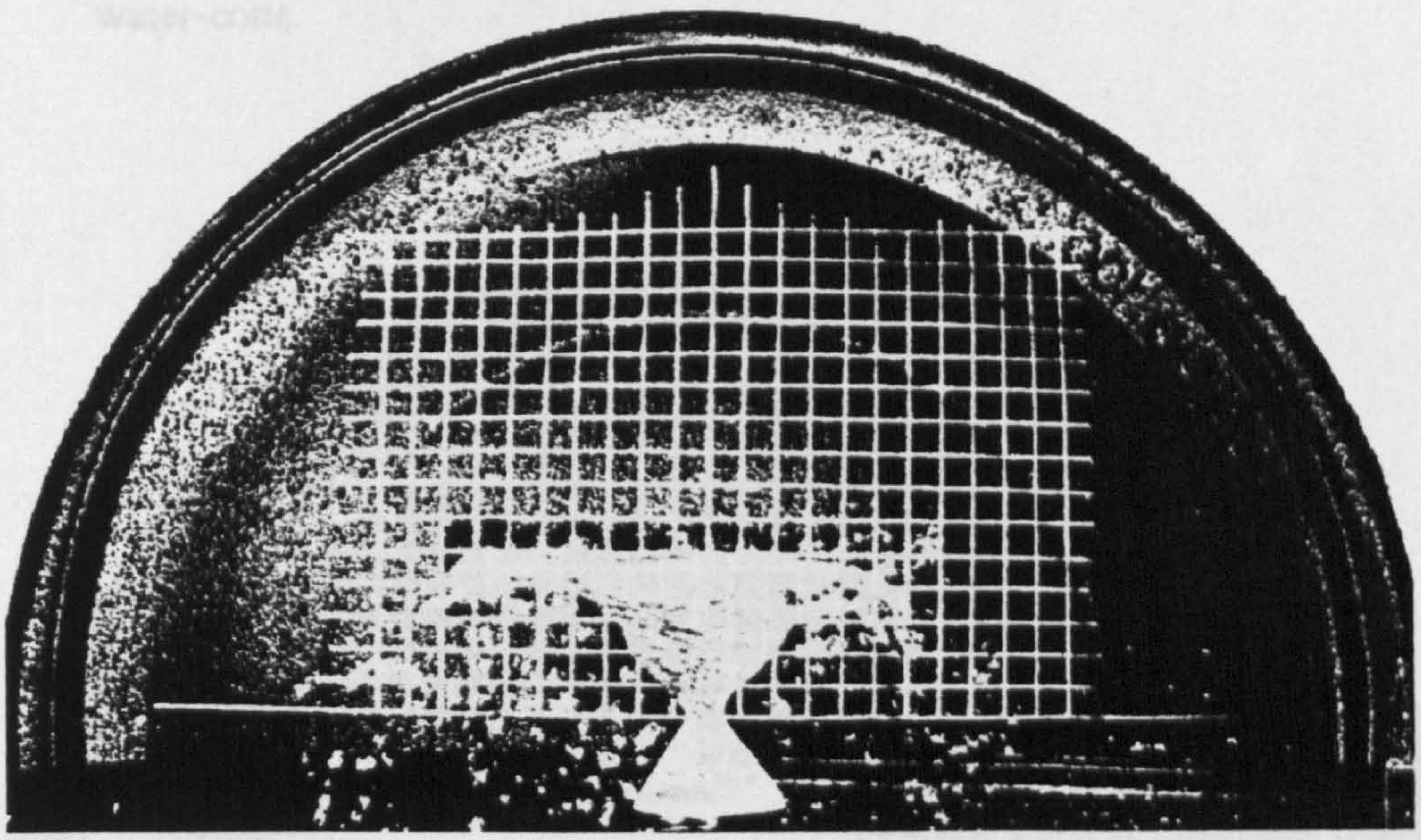


Figure (72)

❑ Experiment 18

Maintaining the size of the orifice at 18 mm, I have examined the change of the emissions by altering the angle of the jets. In this experiment and the following three, the jets are set at an angle of 22.5°.

Variables:

- Eight jets at the angle 22.5°
- 18mm orifice.

Results:

The eight jets here produced a little wider water-cone, that is very similar to that of experiment 16, figure 73. Therefore, we may gather that the angle of the jets has a delicate role in determining the centrifugal action of the emitted water-cone.

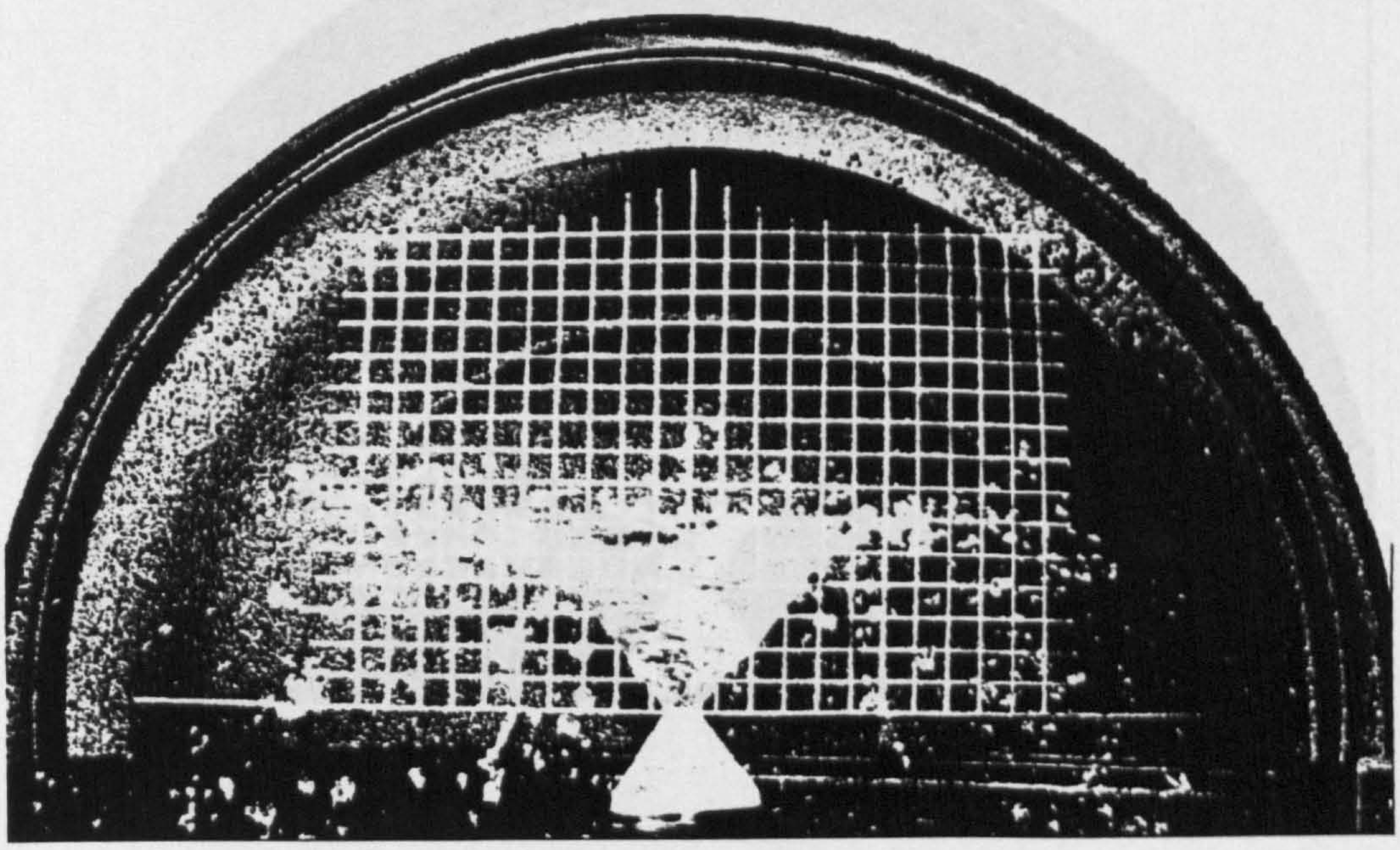


Figure (73)

Experiment 19

Variables:

- Six jets at the angle 22.5°.
- 18mm orifice.

Results:

Figure 74 shows the six jets used here have created a wider and higher water-cone, but that the curvy end on the top is largely lost. This is due to the difference in the angular momentum and the different balance with the surface tension on the water-cone's wall and gravity. The breaking up of the water-cone creates smaller water-drops that scatter in a wider circle.

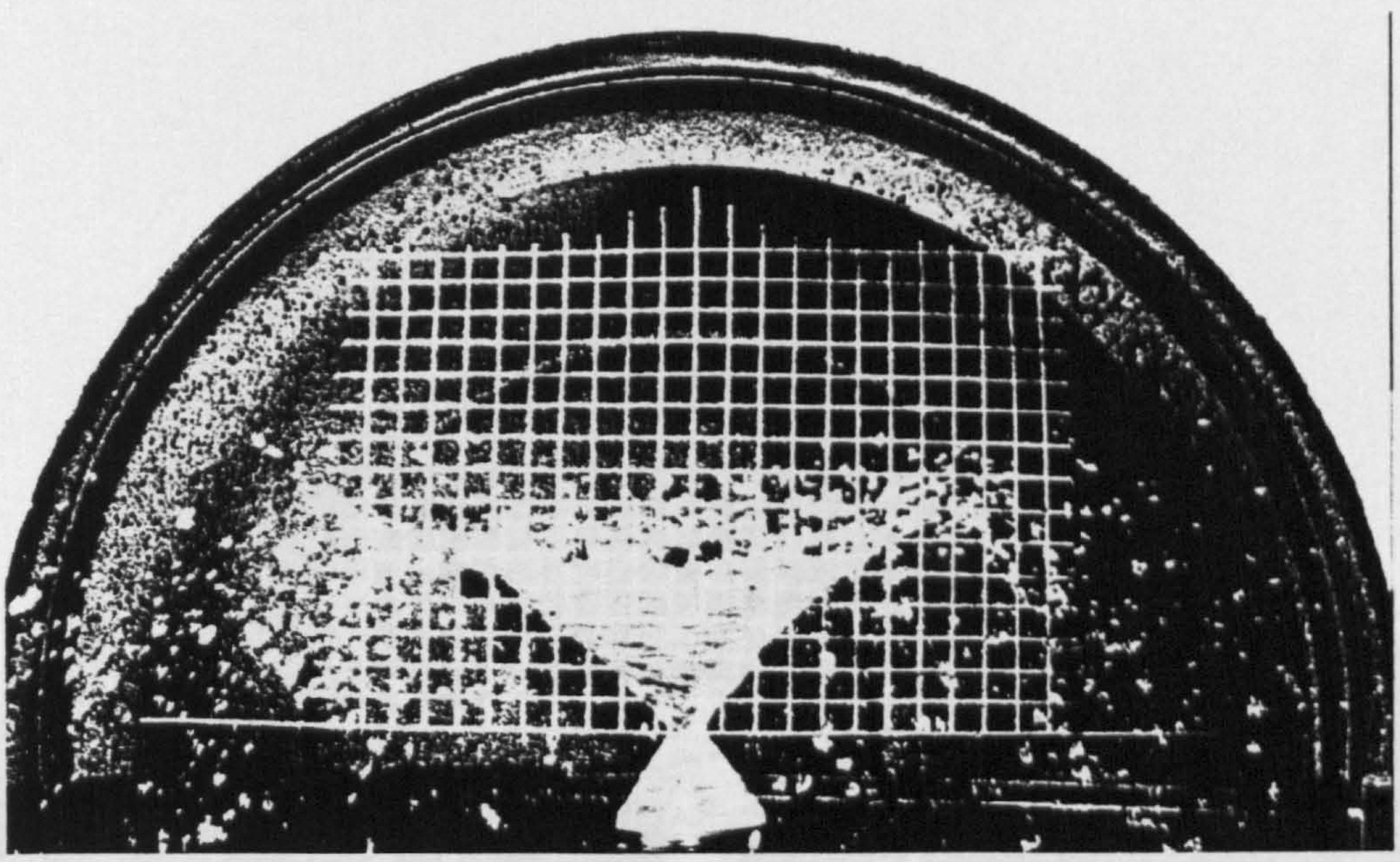


Figure (74)

Experiment 20

Variables:

- Twelve jets at the angle 22.5°.
- 18mm orifice.

Results:

The twelve jets used in this experiment produced a much thicker water-cone with a wider curvy-end than experiment 18. The great volume of water that flowed into the fountain-head built the thick wall of the water-cone that broke up into big water-drops, falling within a small circle around the fountain-head, figure 75. To compare this result with the similar experiment eight, we find that the two-millimetre difference in the orifice's diameter dropped the height of the water-cone by almost half, due to the reduction of the water-pressure in the orifice.

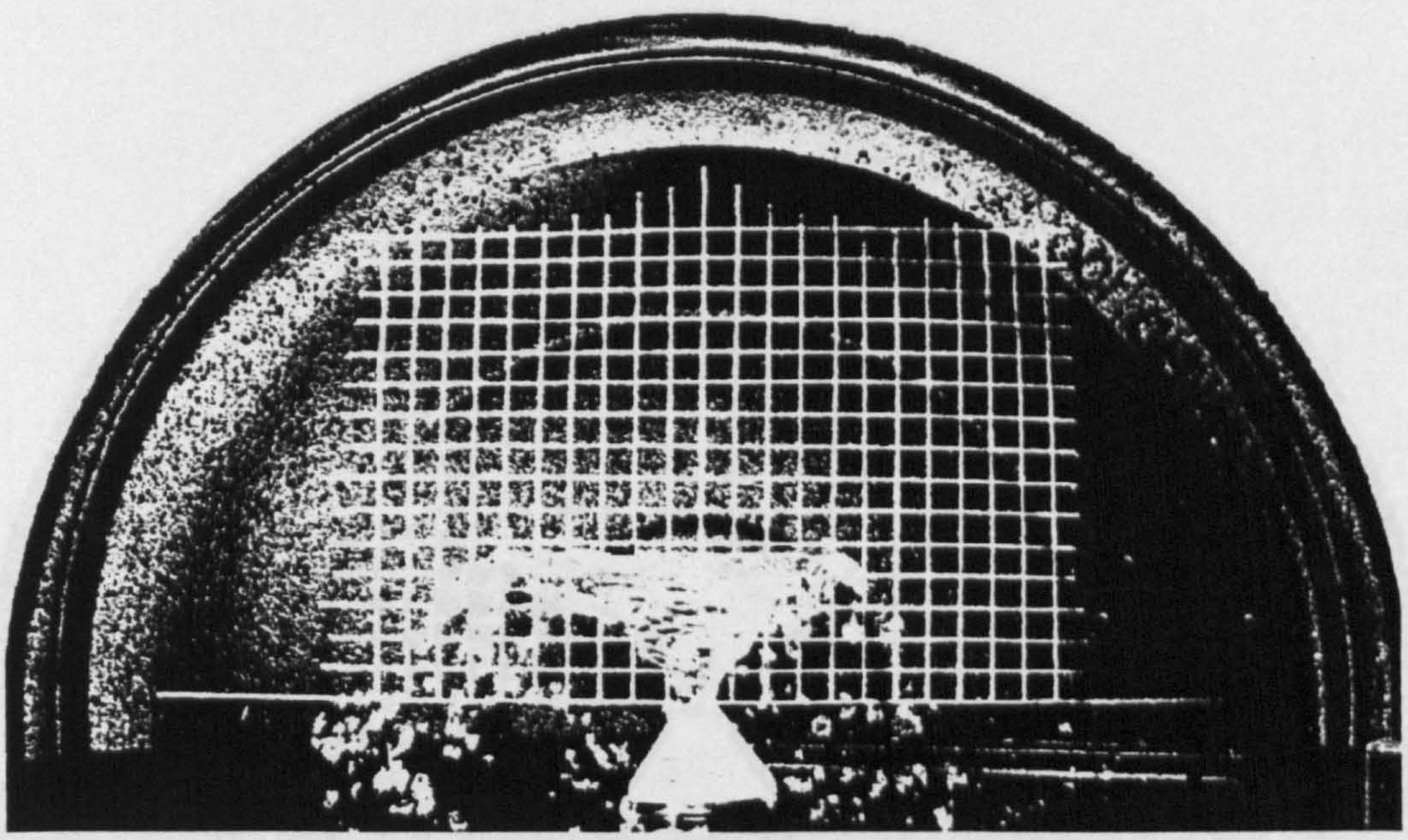


Figure (75)

❑ Experiment 21

Variables:

- Three jets at the angle 22.5°.
- 18mm orifice.

Results:

When comparing the result of this experiment with that of experiment seven, which has the same setting except the size of the orifice, we find that the breaking up of the water-cone tends to be into bigger water-drops. These water-drops also fall within a smaller circle than in experiment seven, which is due to the decrease of water pressure at the orifice and consequently a thicker wall is created. Figure 76 shows a wider and lower water-cone.

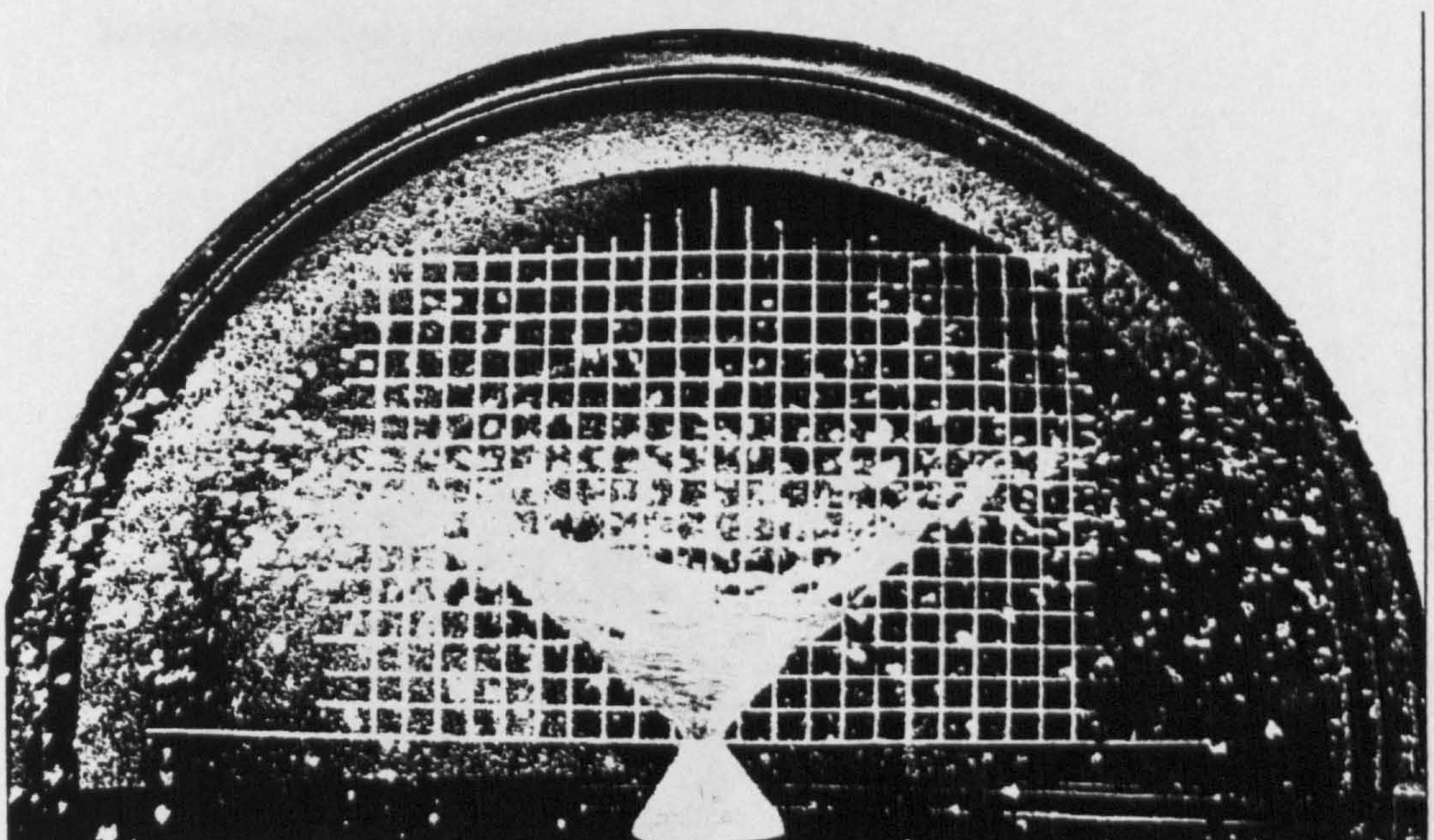


Figure (76)

Experiment 22

The conclusion I have drawn from the previous experiments that the 6 jets, 8 jets and 12 jets produced the best emissions. Therefore, I set a re-examination of these numbers of jets, in this experiment and the next three, using a 13mm orifice at the same angle of 19.5° and 22.5°.

Variables:

- 13mm diameter orifice.
- Six jets at the angle 19.5°.

Results:

This experiment produced a higher and narrower water-cone. The simple fact governing this result is that the water-pressure at the orifice has increased, creating a different shaped emission, which appears like a distorted conic shape. The water-cone, as shown in figure 77, breaks into relatively medium sized water-drops that are thrown into the air, creating a triangular shape, before falling into a wide circle.

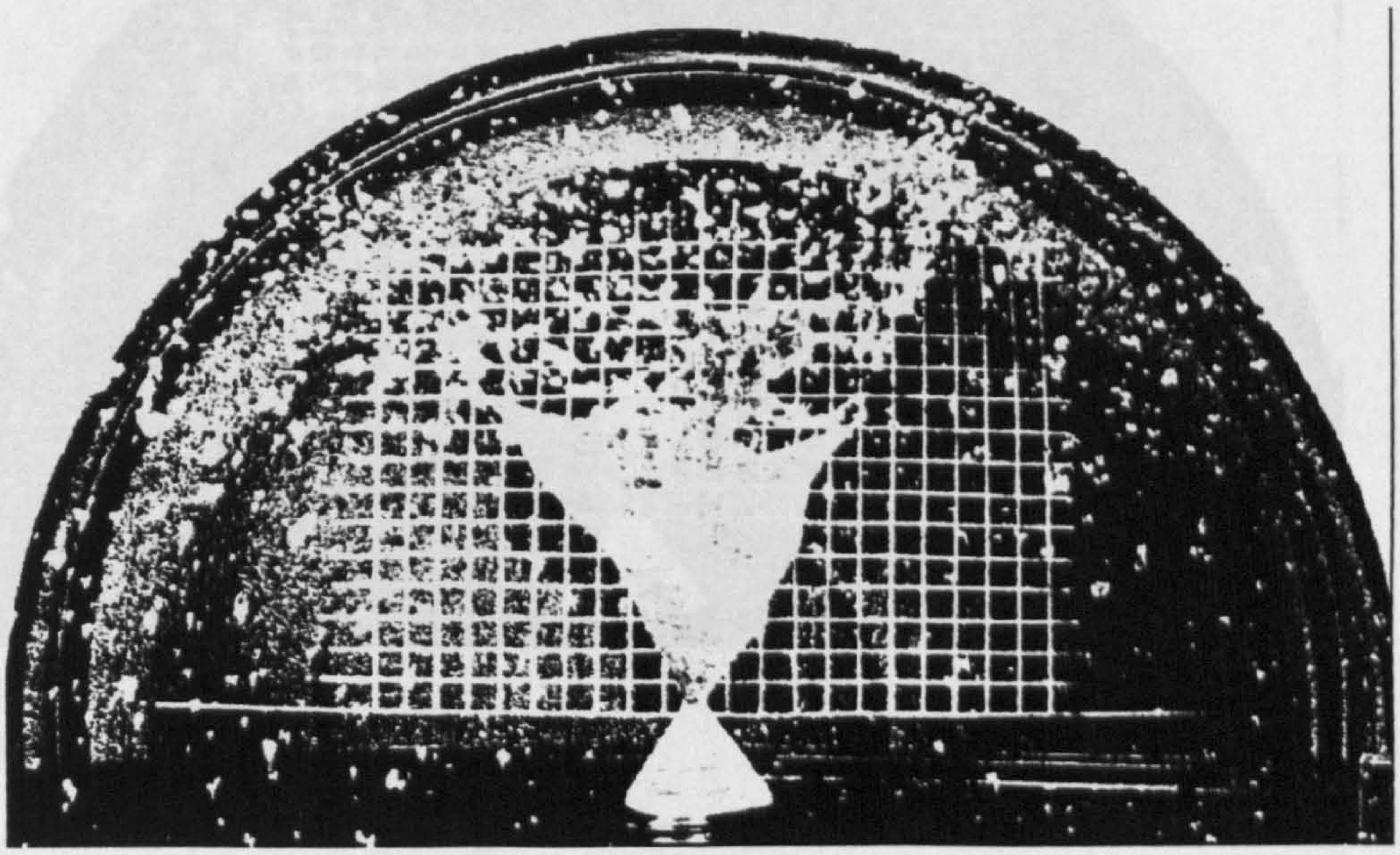


Figure (77)

Experiment 23

Variables:

- Six jets at the angle 22.5°.
- 13mm orifice.

Results:

Figure 78 shows a better emission than the previous experiment. The water-drops are thrown into the air for same distance, at the same angle of the water-cone, before falling into a wider circle than in experiment 22. The projection of the water-cone alongside the small water-drops makes an interesting triangular outlines. In this result the swirl of the water is greater that in experiment 22, whereas the surface tension is less.

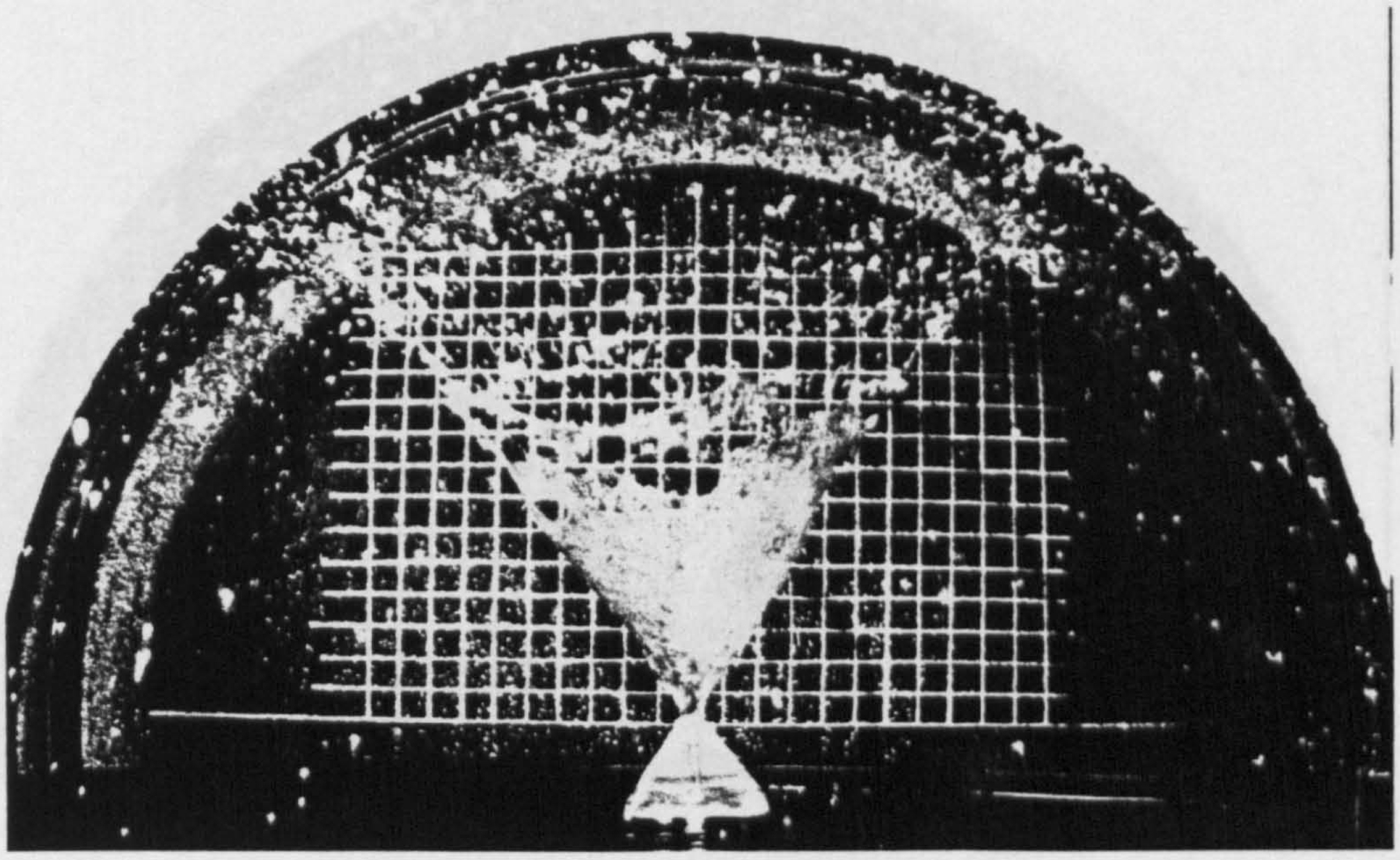


Figure (78)

Experiment 24

Variables:

- Eight jets at the angle 22.5°.
- 13mm orifice.

Results:

The eight jets used in this experiment produced a slightly different shape to those in the previous experiments. Figure 79 shows that the outline of the water-cone starts to lose its straightness, which is due to increased thickness of the wall created by the larger volume of water flowed into the fountain-head.

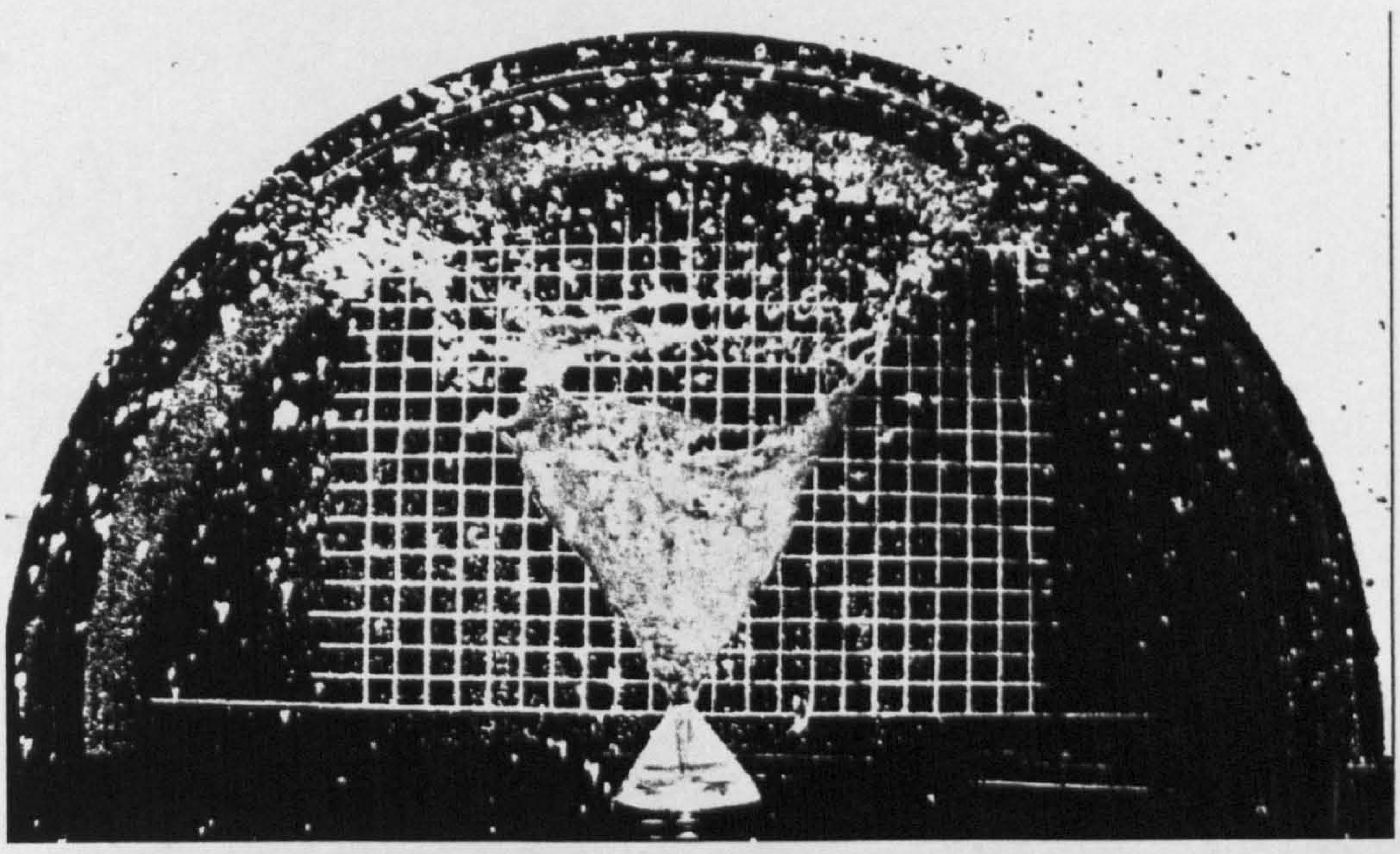


Figure (79)

❑ Experiment 25

Variables:

- Twelve jets at the angle 22.5.
- 13mm orifice.

Results:

The large volume of water which passes through the twelve jets in this experiment tends to produce a different shaped emission. Figure 80 shows that the outline of the water-cone starts to curve in, in other words, this conic shape is beginning to close up from the top. This means that the higher the volume of water and the narrower the orifice, the more closed-end to the tops of the water-cone is likely to be, or less angular momentum.

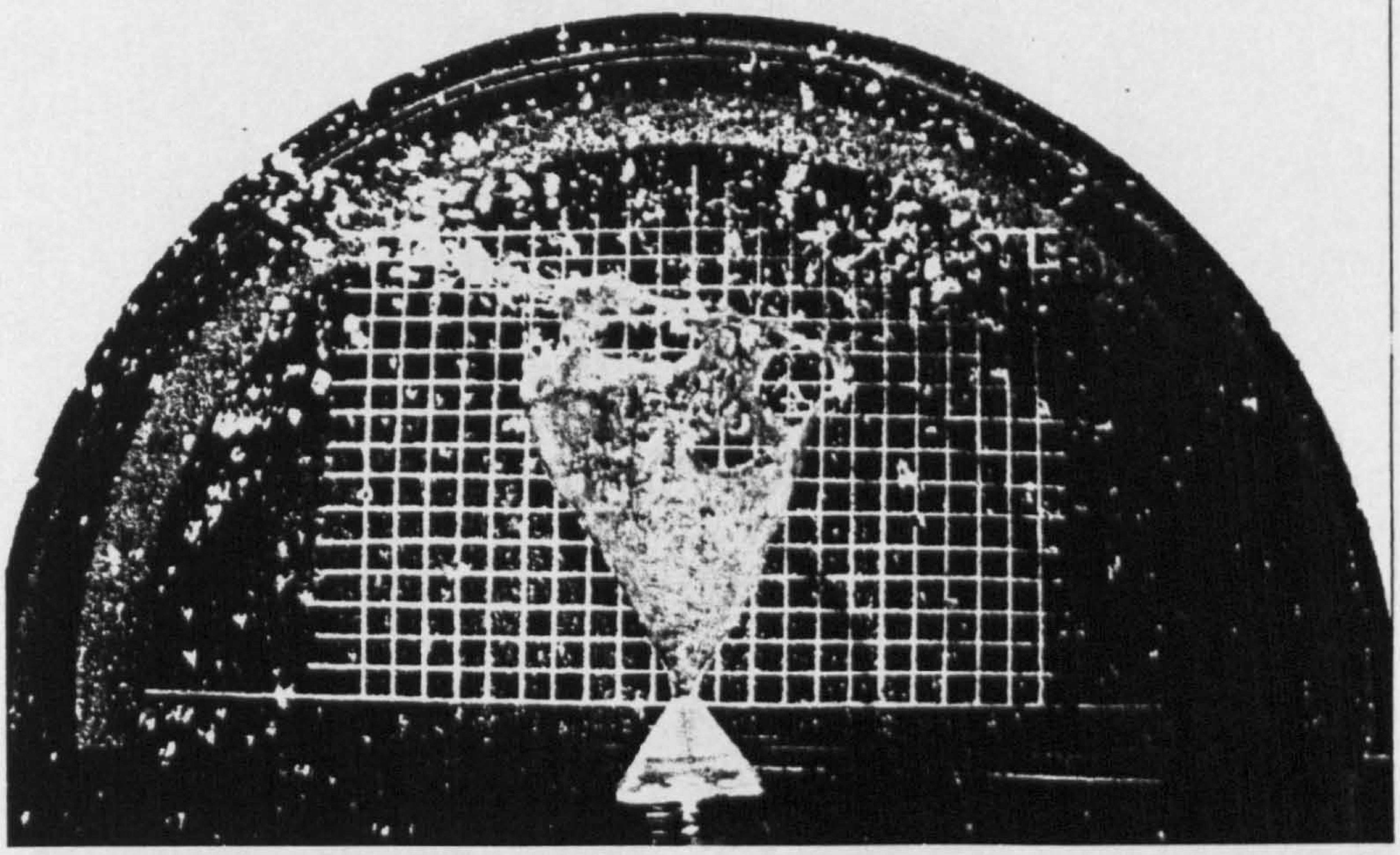


Figure (80)

❑ Experiment 26

In order to examine the effect of the angle of jets, a significant change in the angle of the jets has been introduced in this experiment and the next one.

Variable:

- Ten jets at the angle 10°.
- 16mm orifice.

Result:

The alteration of the angle showed a significant change in the produced shape in comparison to the shape of experiment nine, which has the same setting but differently angled. The less angular momentum produced very narrow and small water-cone which curves out sharply in a vertical line before breaking up into a few large drops, as shown in figure 81. In addition, the very thick wall of the water-cone is characterised by its rough surface.

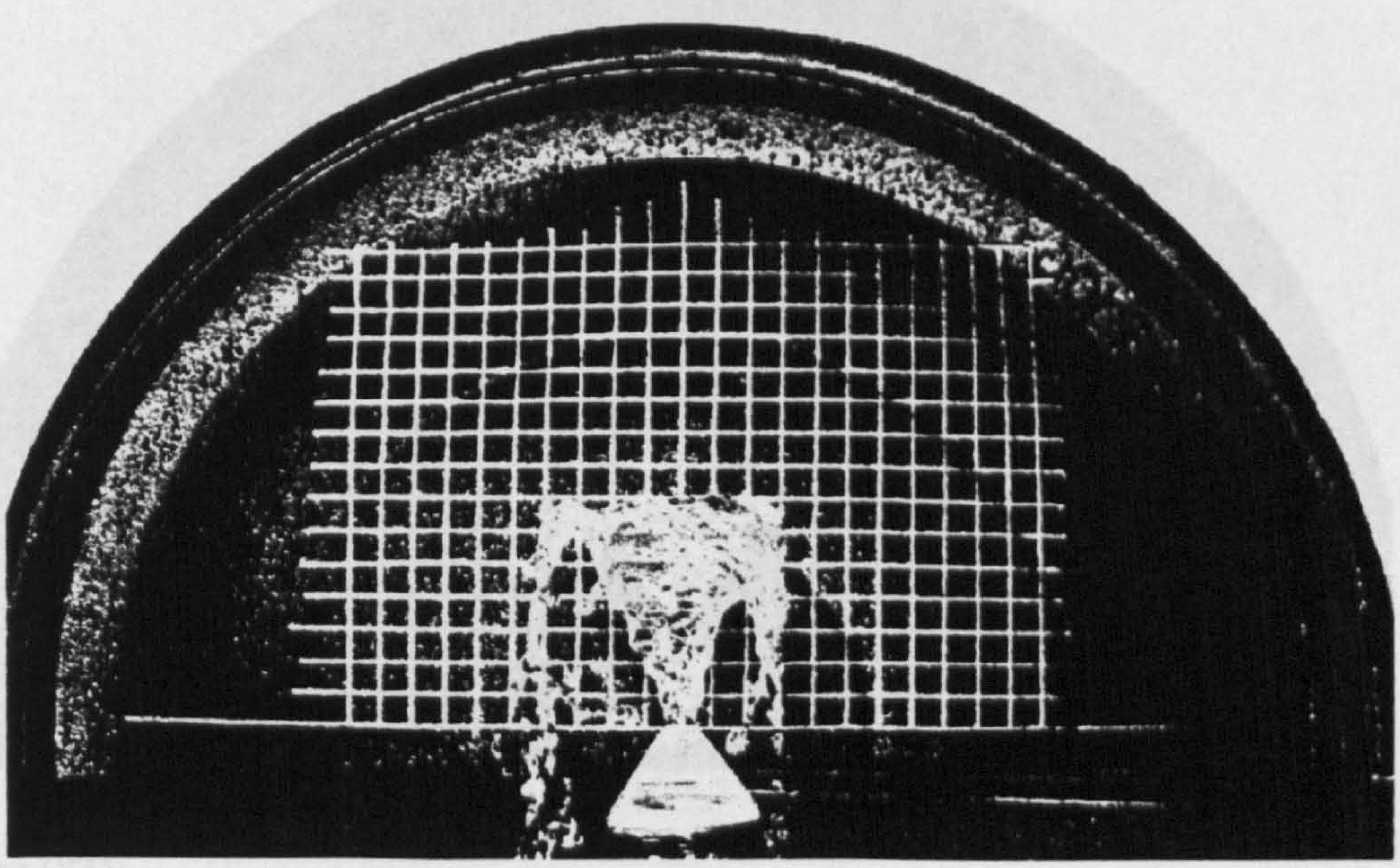


Figure (81)

Experiment 27

Variables:

- Five jets at the angle 10°.
- 16mm orifice.

Results:

This experiment is the same as the previous one, except there are five jets instead of ten. The shape produced, as shown in figure 82, is a smaller water-cone with a very thick wall, which breaks into big drops of water, falling vertically into the pool. It seems from this experiment and the previous one that the angle of the jets did not comply with the other components to create sufficient swirling motion inside the fountain-head, which would produce a firm and beautiful shape.

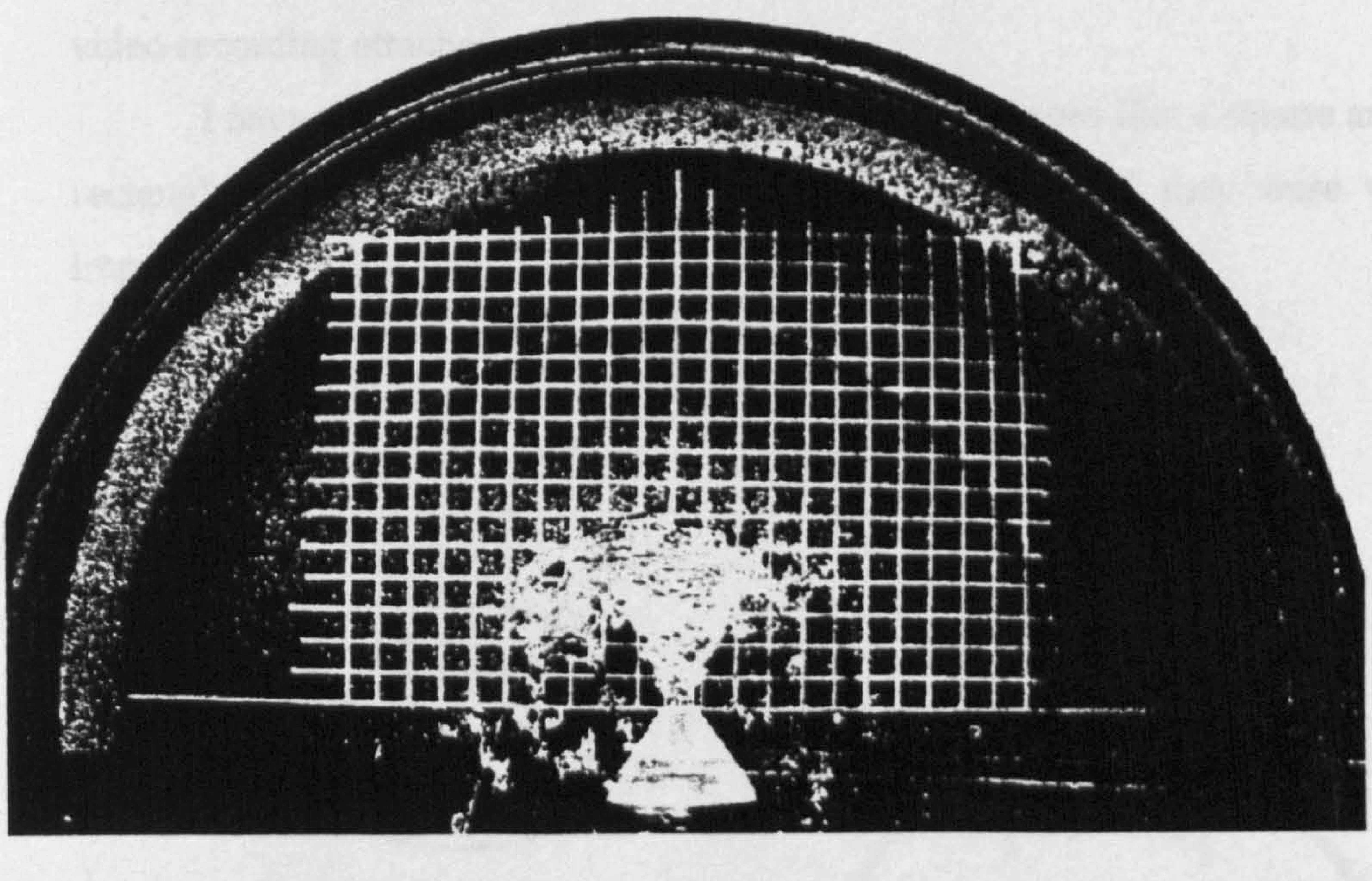


Figure (82)

Experiment 28

In this experiment I have tried to create different shape of emissions from the same fountain-head. I have re-examined the eight jets set at the angle 22.5° with a separate piece that can be placed on top of the orifice of the fountain-head. See figure 83.

Variables:

- Eight jets at the angle 22.5°.
- 18mm orifice with an attachable piece with a triangle shape.

Results:

The attached piece on the orifice has surprisingly, resulted in an upside down triangular pyramid shaped emission, as is shown in figure 84 and 85. The unique thing about this pyramid shape is its firm and flat walls, as well as its sharp edges. The other interesting thing is that most of the water-drops, as the shape starts to break up, collect themselves at the three corners of the pyramid to form three separate streams. This result can be watched more clearly in the video recording attached.

I have tried other separate pieces in different shapes like a square and a rectangle. The results continued in the same pattern, and they were very impressive.

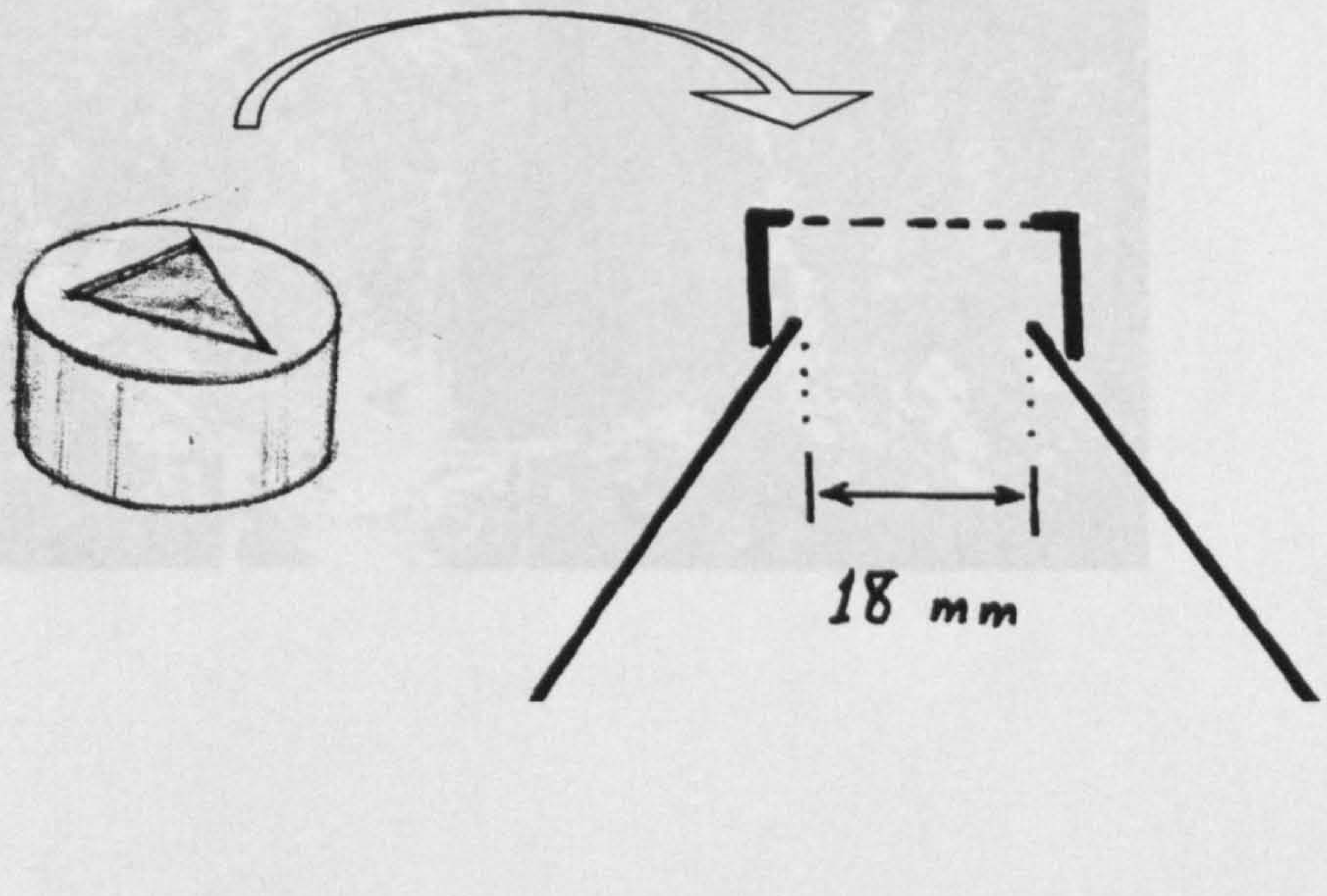


Figure (83)

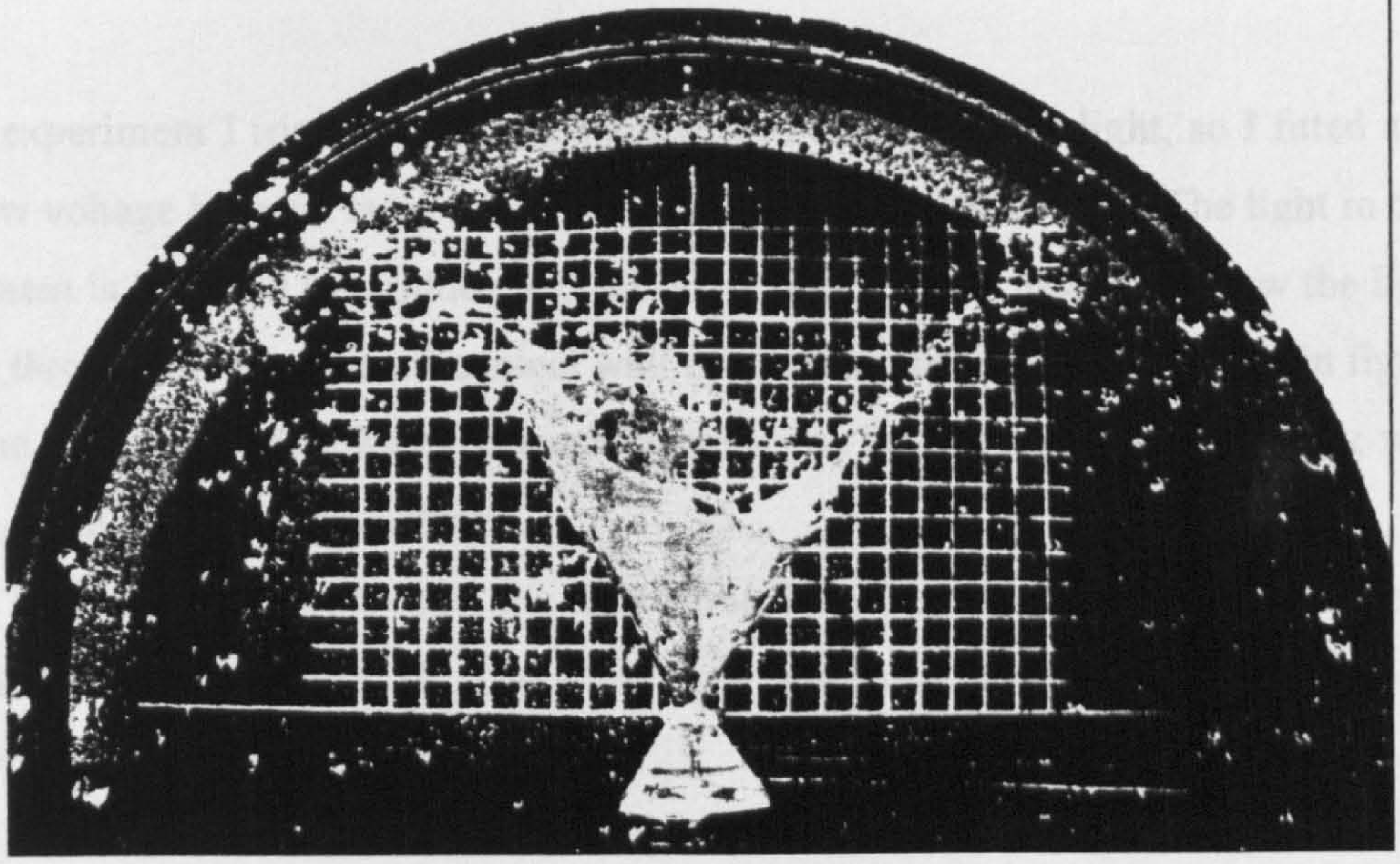


Figure (84)

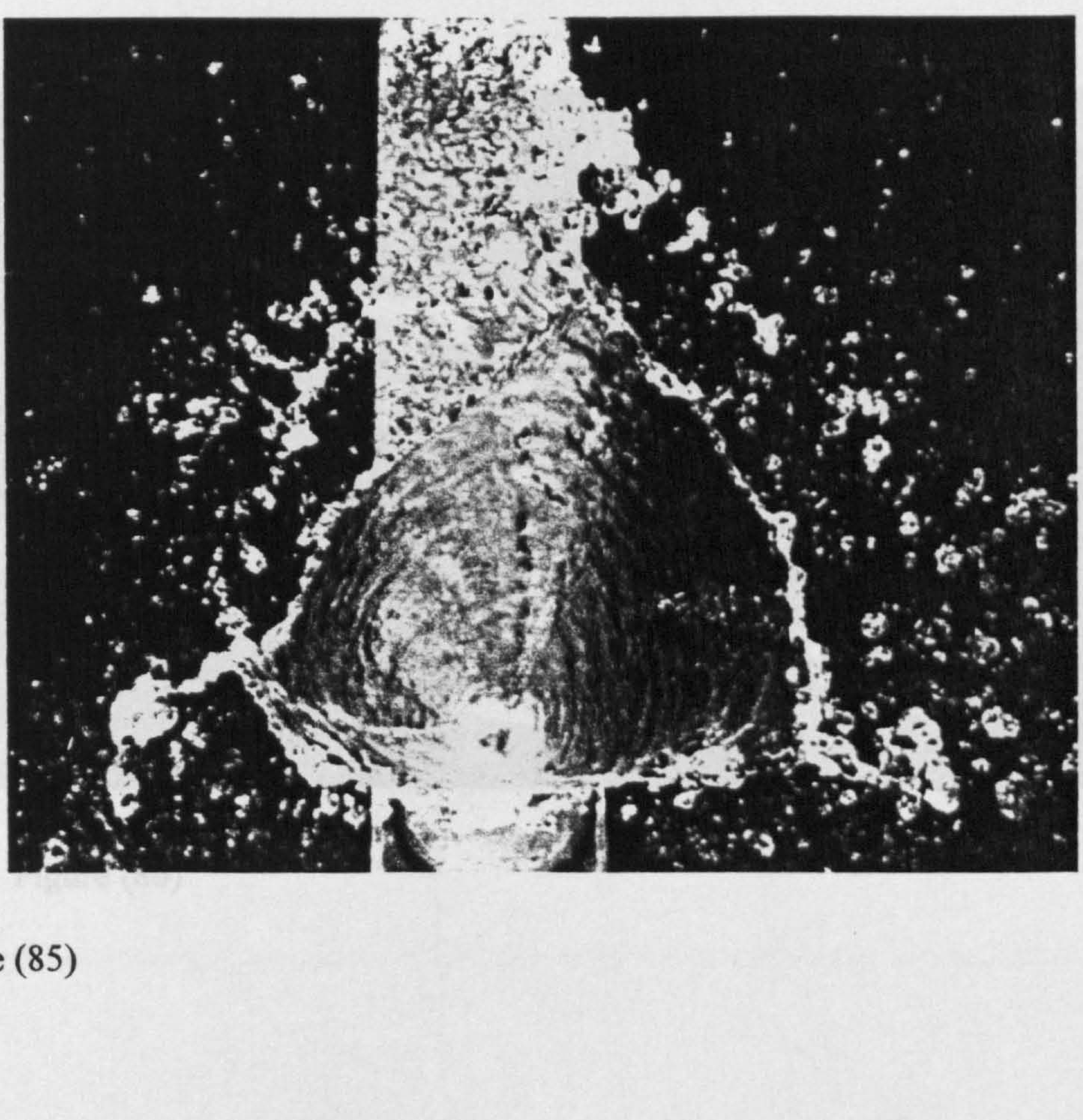


Figure (85)

Experiment 29

In this experiment I tried to examine the effect of using internal light, so I fitted a 5-watt low voltage halogen lamp inside the body of the fountain-head. The light in this experiment is arranged to produce two different effects. The first is to allow the light to pass through the transparent conical wall of the fountain-head as is shown in figure 86. The result was very dramatic as the water-cone is reflected on surrounding wall of area, even on the above ceiling.

The second effect is to let the light shine from the orifice of the fountain-head, as clearly shown in figure 87. The result was more dramatic. Both results can be watched in the video recording attached.

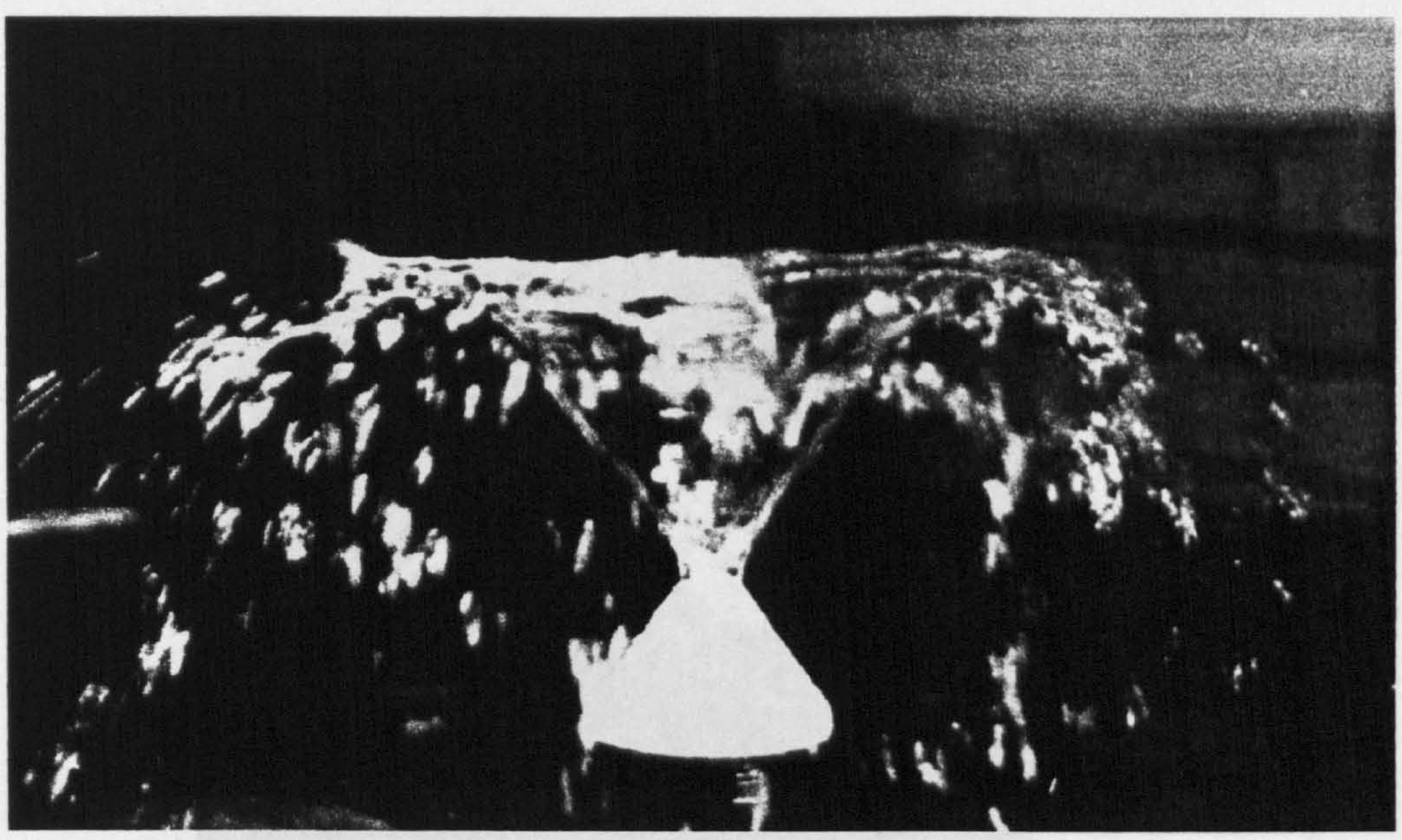


Figure (86)

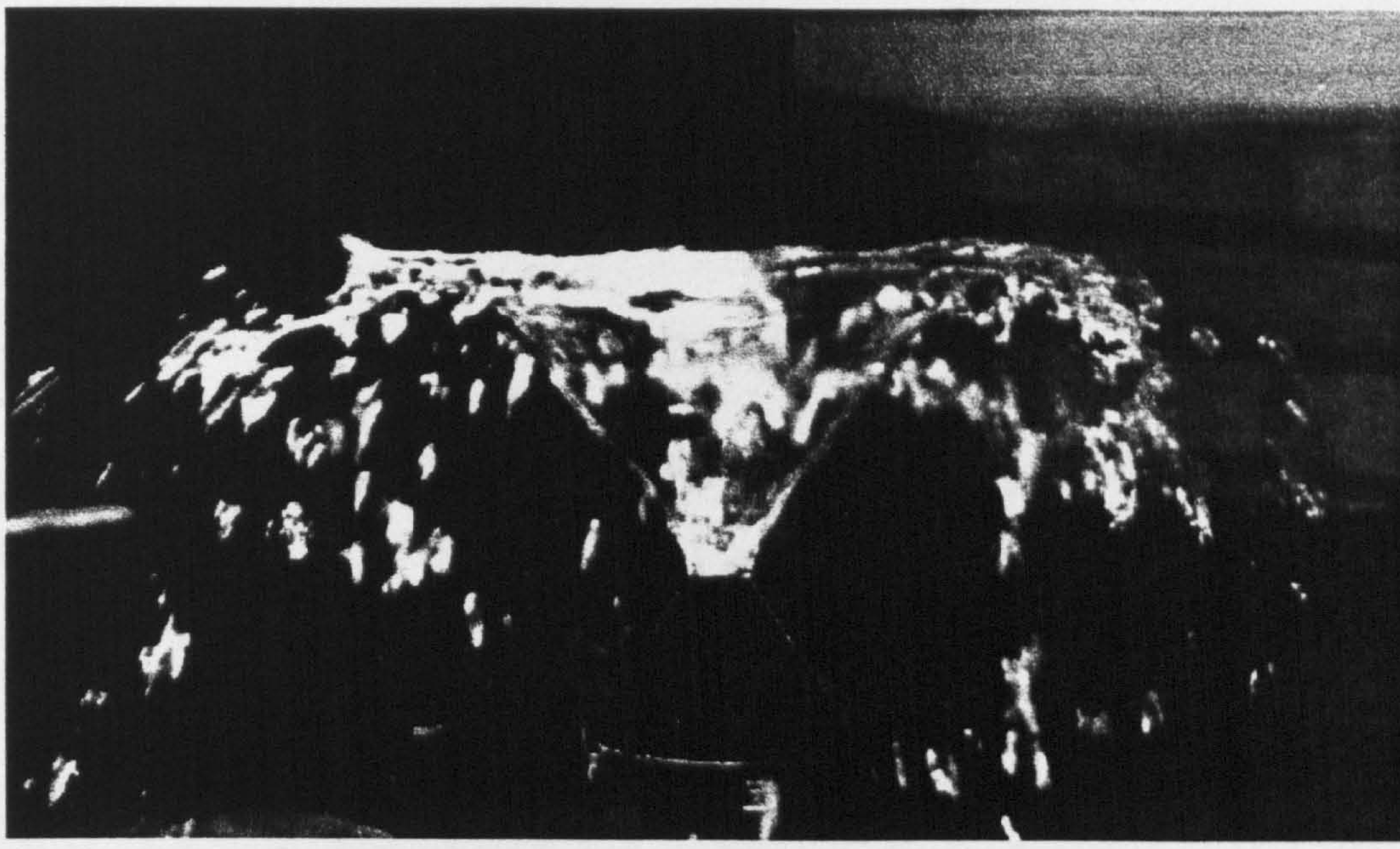
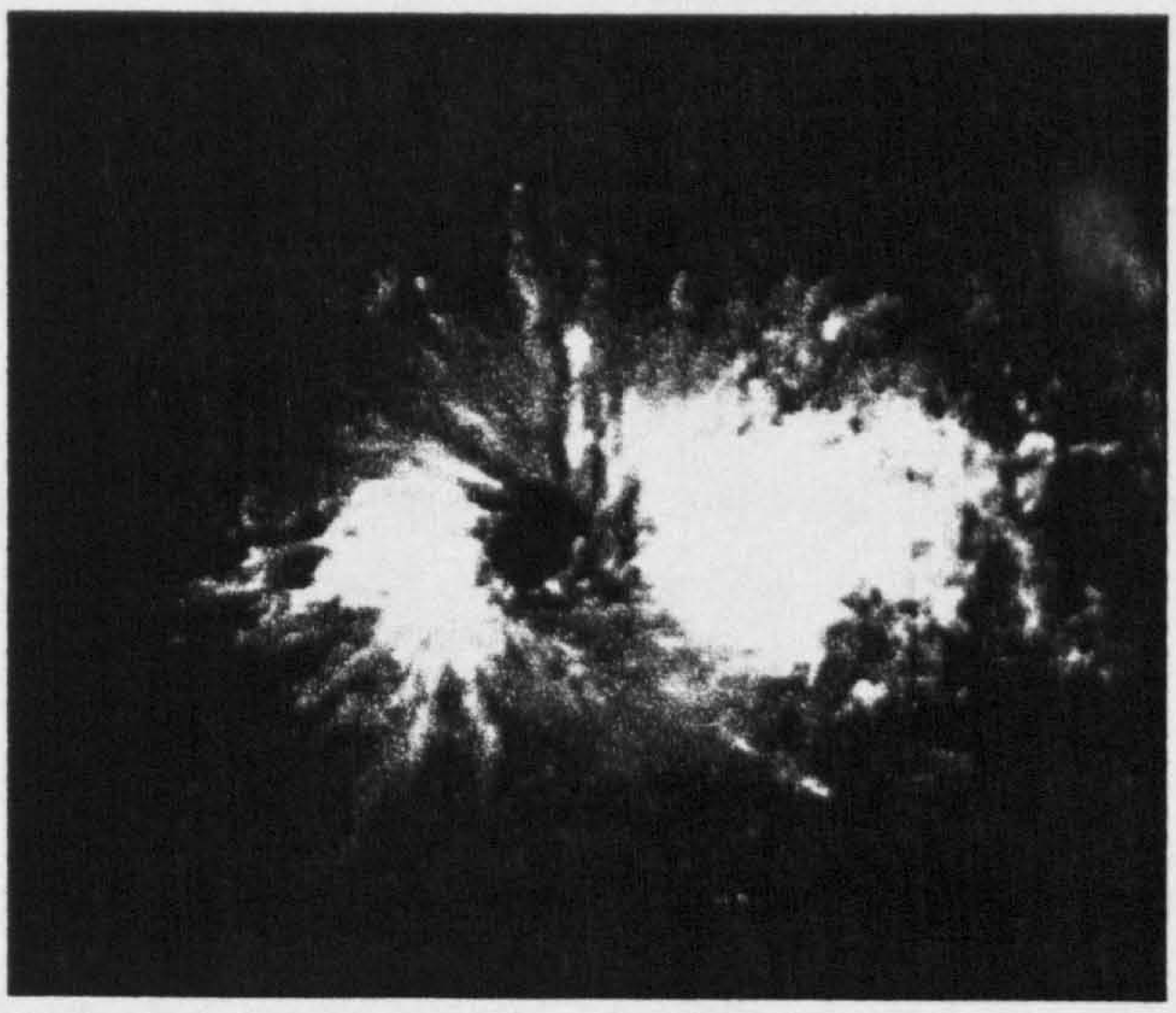


Figure (87)



By using the light through the orifice the swirling motion of the water is clearly shown.

The Fountain Design In the Work of the Second Engineer

Al-Jazari

(13th century)

1. The Engineer and his Book.

In the very early years of the thirteenth-century during the Artuqid's dynasty, Diyar-Bakr (now in south-east of Turkey) was economically prosperous, flourishing and peaceful. Within these propitious conditions the introduction of what is believed to be the only synthetic volume in medieval Islamic engineering. An engineer known as al-Jazari, *Badia al-Zaman Abu al-Izz Ismail Bin al-Razzaz al-Jazari*, composed the most elaborate treatise of its kind entitled A Compendium on the Theory and Practice of the Mechanical Arts, *Al-Jmia Bain al-ilm Wal-amal Al-Nafia Fi Sina'at al-hiyal*. Al-Jazari's achievements came to existence under the patronage of Artuqid's Kings.

Unfortunately, no biography on al-Jazari by historians was documented. What is known about his life is contained in his own account in the introduction of his book. He informs us that, at the time of writing his book, he was in the service of Nasir al-Din (1200-1222), the Artuqids king of Diyar Bakr. He had then spent twenty-five years in the court of the family, having served the father and the brother of Nasir al-Din before him (reigned 1200-1222). To the Nasir al-Din's order, Al-Jazari completed his book sometimes between 1204-1206 AD; he died a few years later.

In his book, al-Jazari offers us a wealth of engineering knowledge. In doing so he tells us a good deal about his career from which we gather that he was a master engineer who highly experienced in all branches of engineering, consciously proud of his rank in the technical fellowship. More distinctly, he was a master craftsman who was willing to write with precision and who has left us an engineering document of paramount importance. The value of this volume does not merely rest on its innovative quality, but it also has laid a cornerstone for the building of Islamic engineering as far as history is concerned.

The interest taken in al-Jazari's work throughout a large part of the Islamic world appears in the number of manuscripts composed, dating from the 13th through to the 19th century. But this interest was not fruitful as nobody appeared to adopt al-

Jazari's ideas and incorporate them in the development of 'useful' mechanical devices.

As yet from an engineering point view in the modern time the most important work on al-Jazari has been the award winning (Dexter Prize) English translation of his book by Donald R. Hill in 1974. Hill was the first to provide scholars and researchers with an outstanding and complete text of al-Jazari's book, together with accurate reproduction of the original illustrations, appending explanatory notes, and modified drawings on some of the devices. He also incorporated an introduction on Islamic technology. The work that Hill presented to us is in deed, unique of its kind and bears a distinguished quality. Hill introduces his view on al-Jazari's book that it is impossible to over-emphasise the importance of al-Jazari's work in the history of engineering. Until modern times there is no other document, from any cultural area, that provides a comparable wealth of instruction for the design, manufacture and assembly of machines[1].

Prior to the publication of this English translation by Hill, attention used to be given by researchers and historians to the published papers on al-Jazari by two German scientists, Eilhard Wiedemann (1852-1928), a physicist with a knowledge of Arabic, and his collaborator, Fritz Hauser, an engineer. Their contribution is considered of substantial importance for the study of the history of Islamic science and engineering. Regretfully, Wiedemann did not publish his findings in the form of a book or a series of books. Most of the articles he wrote were diffused in a number of German Journals, which are today difficult to obtain. Hill affirms that there are several defects which diminishes the usefulness of their work, "inaccessibility" is not the least of which; but their "treatment of the text and the unevenness of the presentation" are the most serious deficiencies. Occasionally, the original text is mishandled either by compression or abridgement[2]. A few years after the appearance of the translated and annotated work by Hill on al-Jazari, in 1979, Ahmad Y. al-Hassan issued the Arabic edition. No explanatory notes were given in this edition; the

[1] Al-Jazari, Ibn al-Razzaz. *The Book of Knowledge of Ingenious Mechanical Devices.* edited by D. Hill (1974) p. 18.
[2] *Ibid.* p.8.

main objective was to offer the people with knowledge of Arabic a coherent edited volume of al-Jazari's book. The work undertaken by al-Hassan and his colleagues was very demanding. Undoubtedly, the effort and the commitment required to edit such a book are not, to a certain degree, any less demanding than composing it. Acknowledging this the editor admits that:

> "It was not always easy to follow the functioning of such devices. The description of each device had to be checked more than once. Frequent resort was made to the English translation by Hill, along with the translator's remarks and explanatory notes. Occasionally, the German translation in the form of articles published by Wiedemann and Hauser was consulted"[3].

Al- Jazari's book in technical terms is very elaborate, and covers different mechanical subjects through six categories. The basic and the longest part, Category I, which discusses a very elaborate water-clock. Category II deals with vessels and figures suitable for drinking, and Category III is on constructing pitchers, basins and other things for hand washing and phlebotomy. The fourth category is devoted to fountains (which this work will concentrate on) and perpetual flutes. Remarkable machines for raising water are included in Category V. Finally, Category VI describes miscellaneous useful things, such as doors and locks.

The format which al-Jazari followed in his book is often lucid and follows a set pattern. It starts with a general description of the machine and how it operates; then this is followed by a number of sections describing the construction of various components of the device with reference to the relevant detailed drawing. The interest of the book emerges in two features. First, the careful description of the manufacture of individual components, and second, the assembly process of those parts to construct the complete device. Al-Jazari's work is not, of course, free from

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[3] Al-Jazari, Ibn al-Razzaz. Al-Jami bayn al'ilm wa l-Amal al-Nafi' fi sina'at al-Hiyal. edited by A. al-Hassan. p. 16.

defects, the most serious lying in a carelessness to provide a proper mathematical and geometric data as well as showing little concern for dimensions and scales.

The importance of his work is not restrained by its pure historical value in terms of Islamic engineering or the history of engineering in general. It goes beyond that, and the techniques as well as some technical applications which were documented are in use to the present time. As a professional engineer Hill reports, concerning this, that:

> "A number of methods still in use today are clearly described by al-Jazari; for example, the use of a plumb-line, static balancing of a wheel, the use of a mandrel to check parts for flatness, and of course the grinding in of valves (...). He also distinguishes quite clearly between the three main types of fit used in modem engineering practice: the push-fit, the sliding fit and the running fit"[4].

Furthermore, an appreciation of al-Jazari's work is reflected as Davison reveals that:

> "Up to the 14th century plain wooden bearings were in use in the West. If this is the case, then al-Jazari was considerably in advance of Western technology in this respect, since all his bearings are metal-to-metal. Different types of bearings He used for different duties and introduced a special term for each one. Because of the great care he took in constructing and tuning his machines it seems more likely that his bearings were at least adequate, particularly when it is considered that in most cases loads were light and running speeds slow"[5].

Broadly speaking, Al-Jazari's engineering achievements go even further; covering manufacturing techniques and engineering ideas which are obviously out of the scope

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[4] Al-Jazari, Ibn al-Razzaz. *The Book of Knowledge of Ingenious Mechanical Devices*. edited by D. Hill (1974) p. 279.
[5] *Ibid.* p. 276.

of this thesis. The focal point of this project is the development of the fountain design. Al-Jazari described six fountains of alternating type through which the tradition of fountain's design in Islamic engineering has been continued. The techniques and mechanical applications which were developed by al-Jazari gave fountain design an innovative dimension in terms of engineering along side, as we may call it, the functio-aesthetical dimension, which forms one of the characteristics of all Islamic Arts and Sciences. About these fountains and their technical qualities, Hill informs us that:

> "The simple fountain must be an ancient invention, but of these more complicated devices, nothing appears to have come to light of an earlier date than Banu Musa. Referring specifically to fountains which change their shape, there are no references in Heron, Philon, or Vitruvius, nor do they appear to have been known in China"[6].

2. Method of investigation.

As far as the fountain is concerned, the objective of this current work is based on the investigation of those fountains designed by al-Jazari. Hill and al-Hassan seem to have been in agreement that some of the fountain models are neither clear in the text nor in the drawings. Therefore, I have undertaken this investigation, which will provide the reader with clearer representations of the mechanisms used in all fountain models. In general terms, through this investigation, I have been able to identify what is unclear about al-Jazari's fountains by examining the work of Hill and al-Hassan. The deficiency of clarity in some work of both Hill and al-Hassan is technically attributed to a couple of points. Firstly, the reproduction of the original drawings of al-Jazari by Hill and al-Hassan made no better readability of the drawing than the actual ones. This, however, does exclude the two modified drawings by Hill combined with his explanatory notes; however, the clarity of one of them is still to

[6] Al-Jazari, Ibn al-Razzaz. *The Book of Knowledge of Ingenious Mechanical Devices*. edited by D. Hill (1974) p. 273.

some extent unsatisfactory. The second point is that the operations of some components attached to the fountain cannot be understood unless the reader consults other applications of the component in an entirely different machine, to that which is described in the book.

Due to the lack of specific references, my investigation has been confined to the available published books of Hill and al-Hassan on al-Jazari's work, since their works are the only publications available of their kind. In addition a copy of al-Jazari's treatise dated 1914, I have discovered in *Dar al-Kutub al-Misryya* (The Egyptian Books House) in Cairo, Egypt which was not known to Hill and al-Hassan; has been used as a supportive reference. This manuscript, however, appears to be the most recent copy of the same treatise of *Topqapi Sari* (Topkapi Museum) Istanbul, which was edited by Hill and al-Hassan. However, the latter at the time was believed to be the finest manuscript among more than ten other manuscripts scattered in several libraries all over the world. The work of al-Jazari, nevertheless, has not been privileged with more attention after the published works of Hill and al-Hassan. Despite the ambitious promise by al-Hassan to provide an annotation on al-Jazari's work in a separate publication, but nothing has come to light yet.

Accordingly, the objective of the investigation has become more focused as far as the fountain is concerned. As this present investigation is not designed to discuss in particular the materials and measurements of each device and its components, no specific data will be given unless any of those components have been examined. In fact, Al-Jazari showed little concern for detailed dimensions, and was careless with his provision of a proper proportion of the devices in comparison with their parts. Nevertheless, a short account on what would have been used by al-Jazari (specifically those used in fountains) is to be introduced, accompanied by a brief description of the techniques involved. In the case of al-Jazari, as it was with Banu Musa, such detailed measurement and proportion were initially based on the surrounding physical technical factors. It is evidently clear that the measurements and proportion of the fountains and their devices needed to give adequate static-head emissions from the fountains above the pools would rest on a high profile of land surveying techniques of that time.

Through the development and testing of some components I have been able to present a clear understanding of the principles involved and their specific function within each application. The following work is intended to investigate and represent a clarified image of each model, in the same manner that I applied to Banu Musa fountains.

3. Materials, measuring units and techniques.

Al-Jazari and other engineers and craftsmen alike used a variety of materials; copper, iron, and bronze which were the most common materials then. Al-Jazari made his axles of wood, copper or iron chain as well as of copper or iron depending on the need. There is little of special interest in al-Jazari's use of non-metallic materials, most of which were common substances which had long been in everyday use. Wood occurs frequently, of course, in wheels, axles and structural work. Other materials used were cloth, leather, Sandarac oil, paints, paper, and papier-mâché. However, the use of lamination to produce a wheel that would not warp is of interest.

Techniques used by al-Jazari varied according to what was required; from as ancient a technique as soldering to what he used extensively such as nails, cotters, lugs, male-female joints and push-fit connections. Pipes were made by bending sheet copper to a circular cross-section and soldering the edges together. Those pipes were joined together by making the end of one wider than the end of the other, and pushing the two together. The wide end was called 'female', the narrow 'male', exactly as in modern technical terms. Occasionally pipes were made of brass. Short lengths, particularly where accuracy was of importance, were cast in bronze. When pipes were to be bent they were first filled with lead, bent, and the lead then melted out. Al-Jazari's description of the fabrication of a valve which is prepared from cast bronze is of great interest. This is done with the greatest precision since this is one of the most important and essential parts of the works.

Al-Jazari used the units of weights and measures, which were in everyday use for centuries. Here is a classification of the units:

Weights	1 *Dirhem*	= 3 gr.
	1 *Mithqal*	= 4.5 gr.
	1 *Uqiyya*	= 150 gr.
	1 *Ratl*	= 1850 gr.
	1 *Mann*	= about 1000 gr.= 1 kg.
Measures	1 *Thyra'a* (cubit)	= 0,50 Metre
	1 *Shibr* (span)	= 0,50 *Thyra'a* = 25 cm.

The span (*Shibr*) is the distance between the tip of the thumb and the tip of the forefinger, when the hand is outspread. 12 fingers make up the span, placed side by side. Each finger width was thus equivalent to 2 cm. Another hand's dimension the (*fitr*) is the distance between the tip of the thumb and index finger, when outspread. This is considered to be about 16 cm. Small dimensions are given by the width of a barleycorn *(sha`ira)*. Laid 'belly to back' there were six barleycorns to one finger. The *sha`ira* was therefore equal to about 0.30 cm. Al-Jazari also uses (*zufr*) which is the breadth of a fingernail, perhaps around 1cm. To indicate very small distances he uses the width of a nail-paring *(qulama)*.

3. FOUNTAIN NO. 1,2

3.1. About the fountains.

The first and the second fountains of al-Jazari were operated by the same mechanical concept (fig. 88, 89). Fountain (2), however, was merely an elaboration of fountain (1). Therefore, I will combine my annotation of both fountains in a single presentation. Al-Jazari introduced an innovative concept of an alternating mechanism that he mentioned as a novel idea, which had been invented by him. The concept was based on a **tipping bucket** that controlled the interval-time (see figure 93). A house for the machinery was built at some distance from a pool or a basin in which the fountain was located. A current source of water was allocated for the machinery to provide a sufficient flow of water for operating the fountain. This water supply should have been connected to a river, spring, etc; and essentially drain was linked to the system. The machinery's house must have been installed high above the pool, in accordance with the land surveying techniques, to provide an adequate static pressure, which would give satisfactory emission from the fountain-head.

3.2. Discussion of Hill's and al-Hassan's works.

- The reconstruction of the fountain drawing by Hill (fig. 90) gives, relatively, a clearer picture of the machine. But, on the other hand, a very important part of the mechanism, the counter-weight, was omitted, possibly it was taken for granted by Hill. It is unlikely that Hill could have ignored such an important part of the mechanism. No description was given about it, yet it has had a fundamental operational role. Al-Jazari, however, had described its construction in different places in the treatise, despite the fact that the drawing was to a certain degree confusing. These drawings were also reproduced by al-Hassan, but in general provide no more help to arrive at a full understanding (fig. 91, 92). In the drawing I have illustrated in figure (93) the counter-weight that attached to the bottom of the tipping-bucket, clearly, was set to force the bucket to tilt back after pouring out the water with which is was filled. This by no means contradicts the unclear drawing of al-Jazari (fig. 88, 89) in which the counter-weight looked as if it was fixed to the bottom of the tank. The text on this particular component suggests the same.

- Hill provided no complete diagrammatic explanation on the tipping-bucket mechanism since he has given a full annotation on the operation process of the fountain[7]. The drawings of both Hill and al-Hassan show a vertical projection fixed to the rear end of the tipping bucket, which practically, does not fulfil its function. To clarify this; the meeting point between the top end of the projection and the bottom edge of the balance-pipe need to be increased in order to lift up the balance-pipe and cause it to tilt. With a vertical projection it is unlikely to happen. But an inclined projection would have increased the diameter of the meeting point, and consequently this causes the balance-pipe to tilt towards the adjacent tank (fig. 93).

3.3. Construction of the device.

The machinery of both fountains is exactly the same, and consists of four main components. The following description is to be read in conjunction with Figures 93 and 94.

a. Feeding tanks:

   Some distance away from the pool, a high housing is built in which a tank is constructed and divided into two tanks (a, b). An axle (f) is fixed on top of the partition between the two tanks with two bearings (e) fitted to its end.

b. Delivery pipes:

[7] See al-Jazari (2), p.263.

Fountain No. (1): A wide pipe (m) descends from the bottom of tank (a) along the way down and terminates at the fountain-head. A narrow pipe (n) descends from the adjacent tank (b) down, where it meets the other pipe and penetrates it, so the pipes terminate together at the fountain-head.

Fountain No. (2): Wide and narrow pipes (m1, m2, n1, and n2) are linked to the bottom of each tank, each narrow pipe is interchanged by inserting it into the wide pipe of other tank. Each doubled pipe is laid into a pool and is brought up vertically in the centre of the pool where it is attached to the fountain-heads.

c. Balanced-delivery pipe:

On the axle is a pipe (d) with bent ends oscillating on a central axis fitted to the bearings (e); this is working like the arm of balance. In the centre of this pipe, funnel (g) is attached, into which the supply channel (s) discharges the water. A bleeding-pipe (h1, h2) with an onyx mouthpiece is branched from each side of the pipe, close to its end. The pipe is set in imbalance position where it tilts towards one of the two tanks.

d. Tipping-buckets:

Underneath each of the two bleeding-pipes is a tipping-bucket (k1, k2) shaped like one third of a boat with an axis close to its rear end, rotating in two bearings (j) which are fixed to the walls of the tank. An inclined projection (t), at an acute angle, is attached to the vertical rear end wall of the bucket, its top end meets the balanced-delivery pipe as it is being tilted to its side. To the bottom of the bucket an adequate counter-weight (w) is fitted to tilt back the bucket after it has been poured out its contents.

3.4. Construction of the fountain-head.

As the doubled-pipe (m, n) is brought up in the centre of the pool and above its surface, a brass sphere (p) with six holes in the upper part of the shell is linked to the wider pipe (m). The narrow pipe (n) is passed through this sphere and protrudes a short distance above the top. In the case of Fountain (2) (the doubled version) two similar fountains may be erected in a single pool or each one may be centred in a separate pool.

3.5. How the fountain operates.

Fountain (1): Water runs from supply-channel (s) into funnel (g), then through balanced-delivery pipe (d) into tank (a). Most of the water is discharged into the tank from the end of the balanced-pipe, but some of it tips into the tipping-bucket (k1) through the onyx of the bleeding-pipe (h1). Water descends from the tank running through the wide pipe (m) up to the sphere at the fountain-head to produce six arcs of water in curved jets over the pool. Meanwhile, as the tipping-bucket (k1) is filled for an hour or so it tilts down discharging the water into the tank (a), where at the same time the projection on its rear end lifts up the balanced-pipe, causing it to tilt towards the adjacent tank (b). Then the counter-weight (w) forces the bucket to tilt back to its horizontal position as its contents are being poured out. The operation is repeated in the adjacent tank (b), but the water this time runs through the narrow pipe (n), terminating at the fountain-head to throw up a single jet for the same period of time as the previous emission. So the fountain changes its shape continuously by this repeated mechanical motion as water flows into the machine constantly.

Fountain (2): The mechanism is absolutely the same except that the emission is doubled, as there are two fountains. Each fountain of the two emits a different shape at the same time as both have been fed from one tank. One produces a single jet while the other produces six arcs. The alternation occurs as the balance-pipe is tilted to discharge water into the adjoining tank. Then the fountain that produced a single jet changes to produce six arcs and vice versa.

Figure (88)

The drawing of fountain (1) by al-Jazari. The drawing shows a vertical projection at the rear end of each bucket and the counter-weight as being fixed to the tank's floor. (Reproduced from facsimile of Istanbul, Topqapo Serai's manuscript No. 3472. by Kulture Bakanligi, 1990)

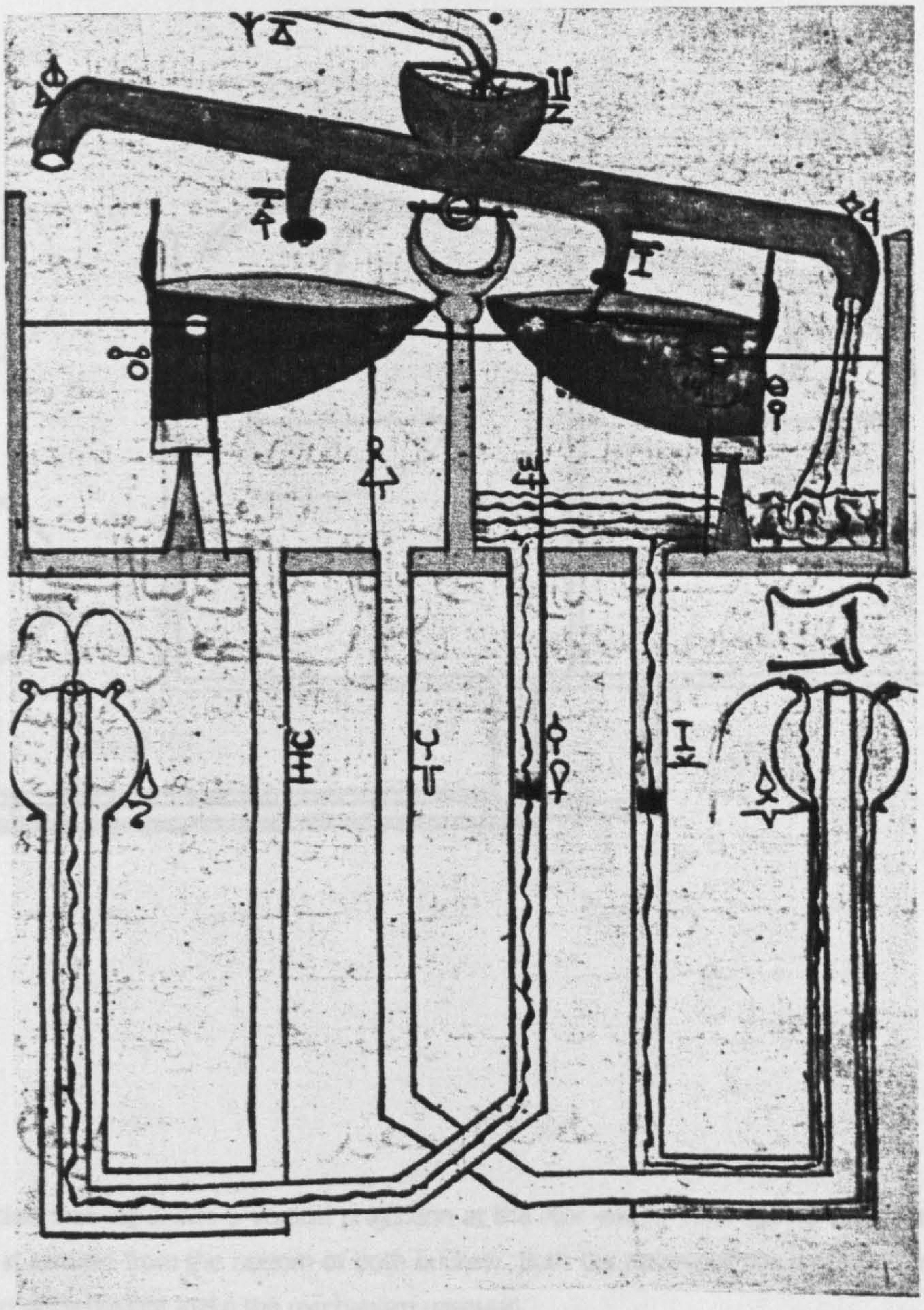

Figure (89)

The drawing of fountain (2) by al-Jazari. The drawing shows the same vertical projection at the rear end of each bucket and the counter-weight as being fixed to the tank's floor. (Reproduced from facsimile of Istanbul, Topqapo Serai's manuscript No. 3472. by Kulture Bakanligi, 1990)

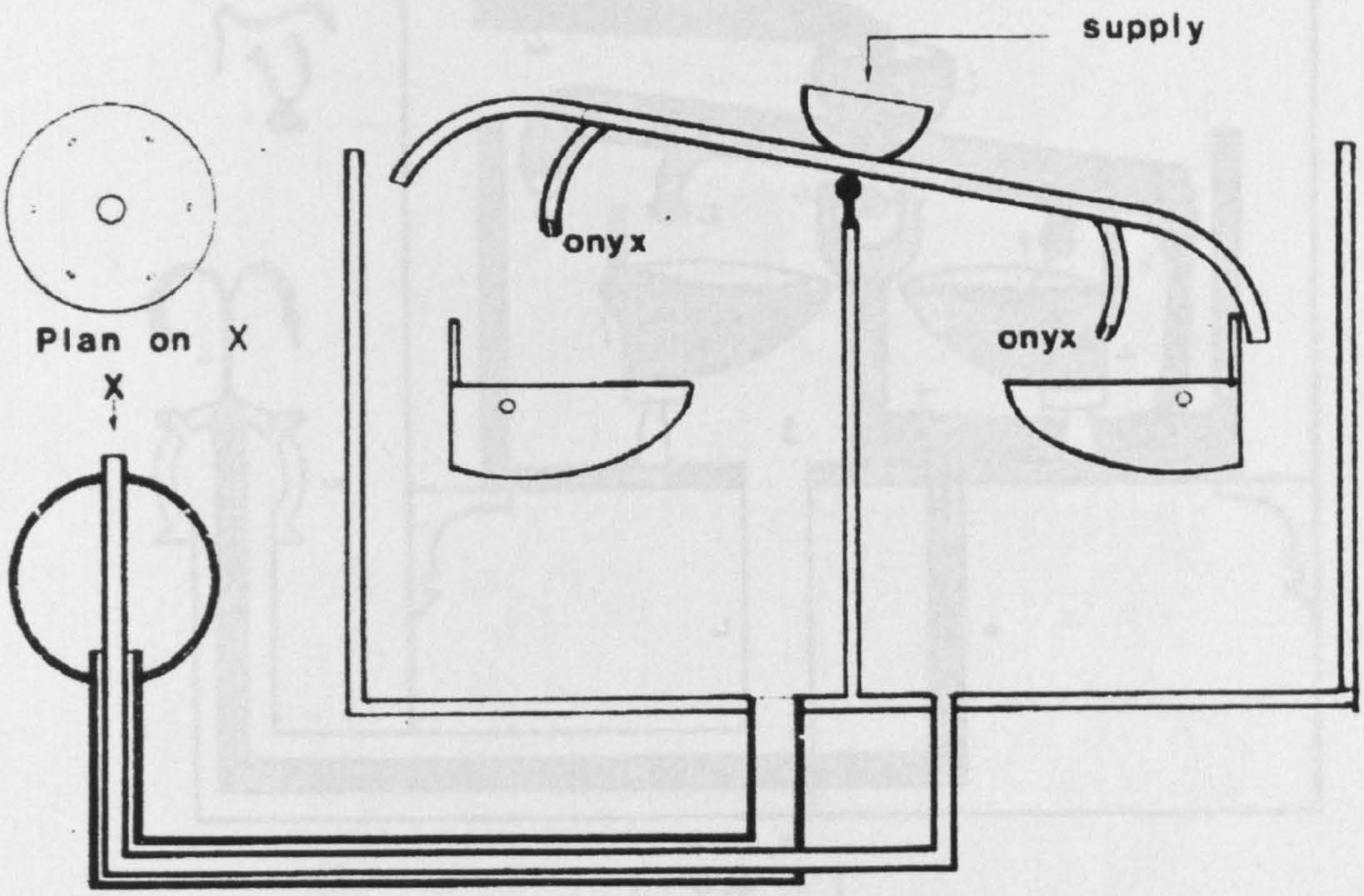

Figure (90).

Hill's reconstructed drawing shows a vertical projection at the rear end of each tipping-bucket and the counter-weight is omitted from the bottom of both buckets. Both the setting of the projection and the absence of the counter-weight make the mechanism unsound.

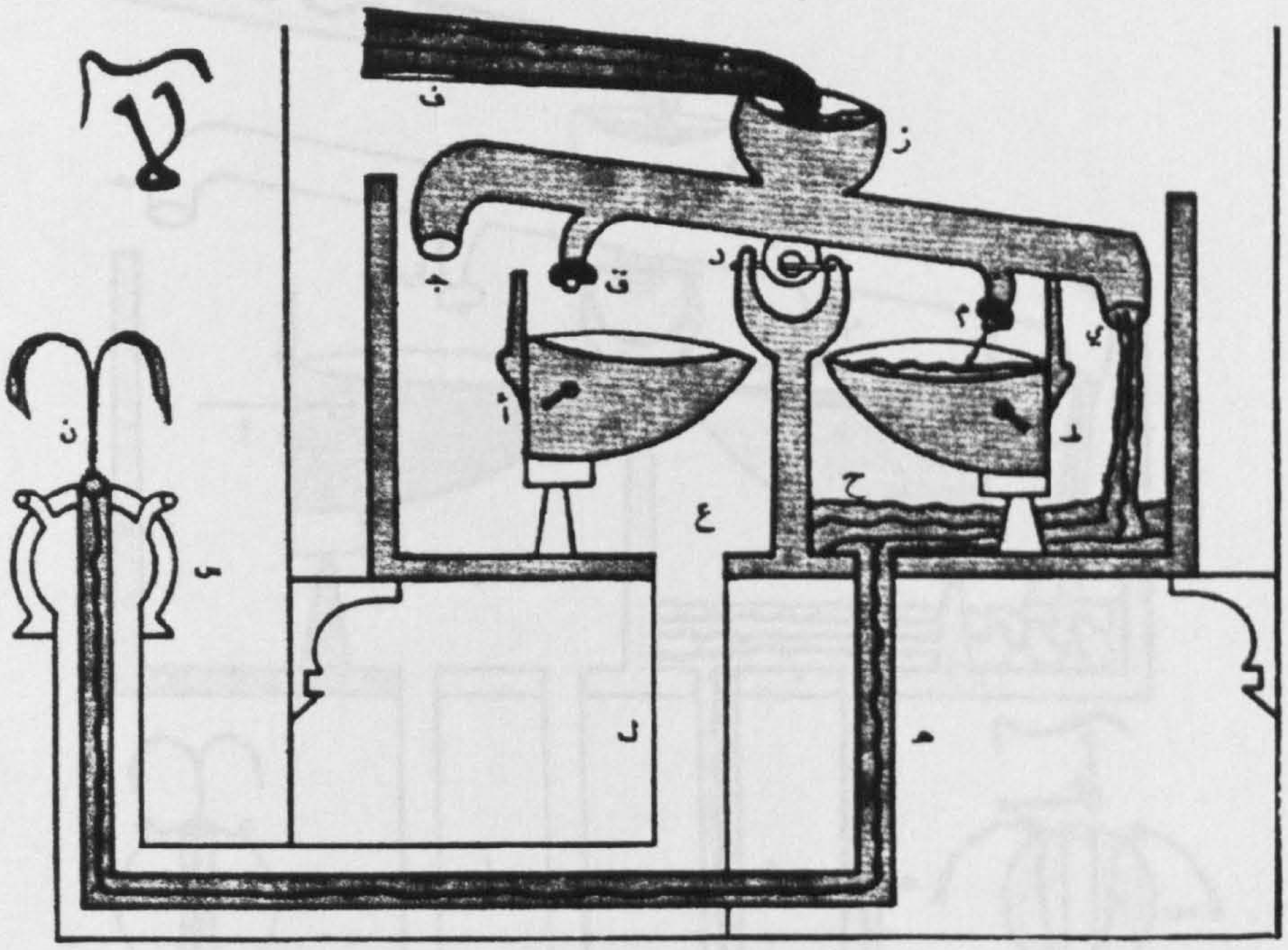

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Figure (91)

Al-Hassan's reproduced drawing of fountain (1), which bears the same ambiguity as that of al-Jazari.

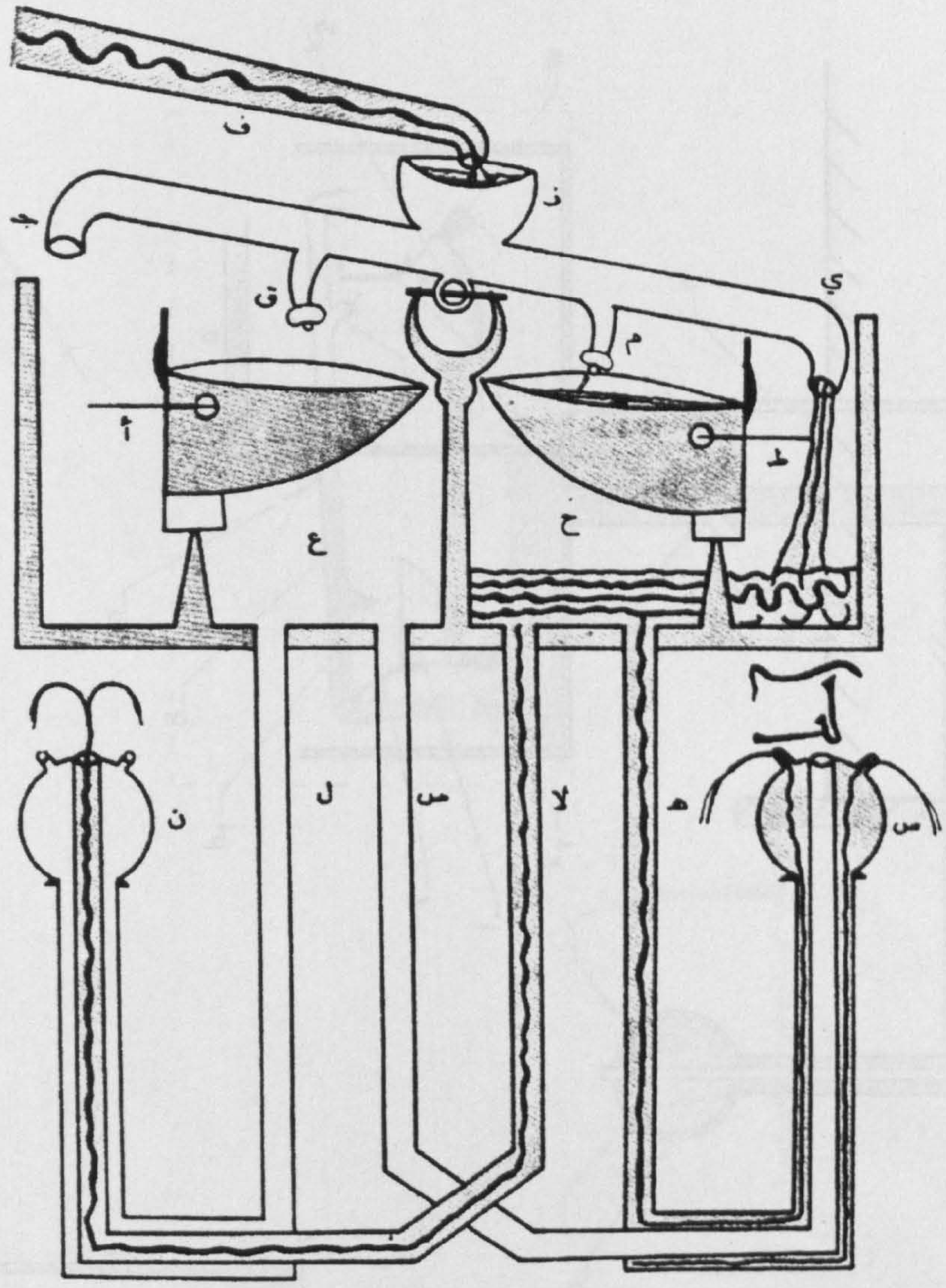
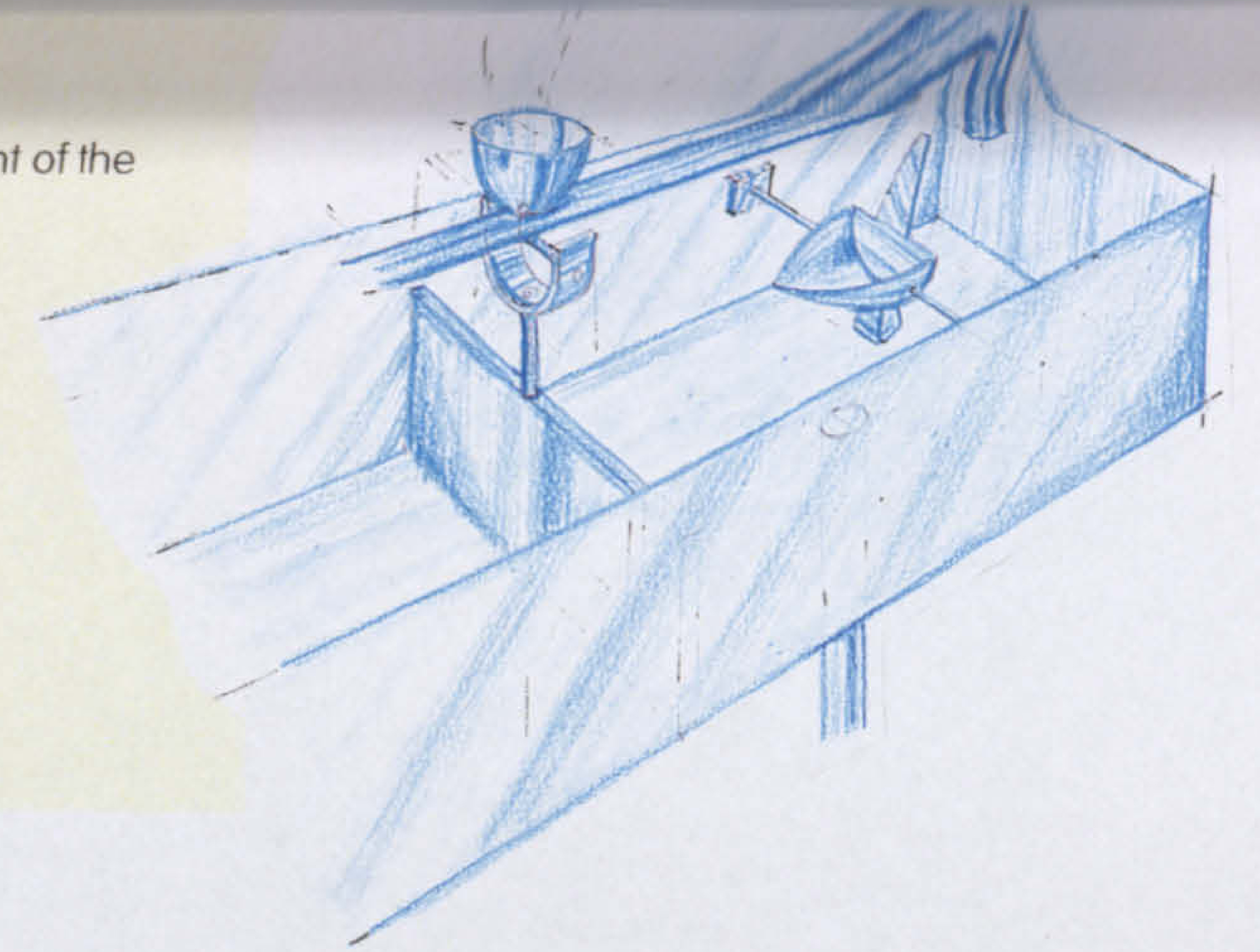
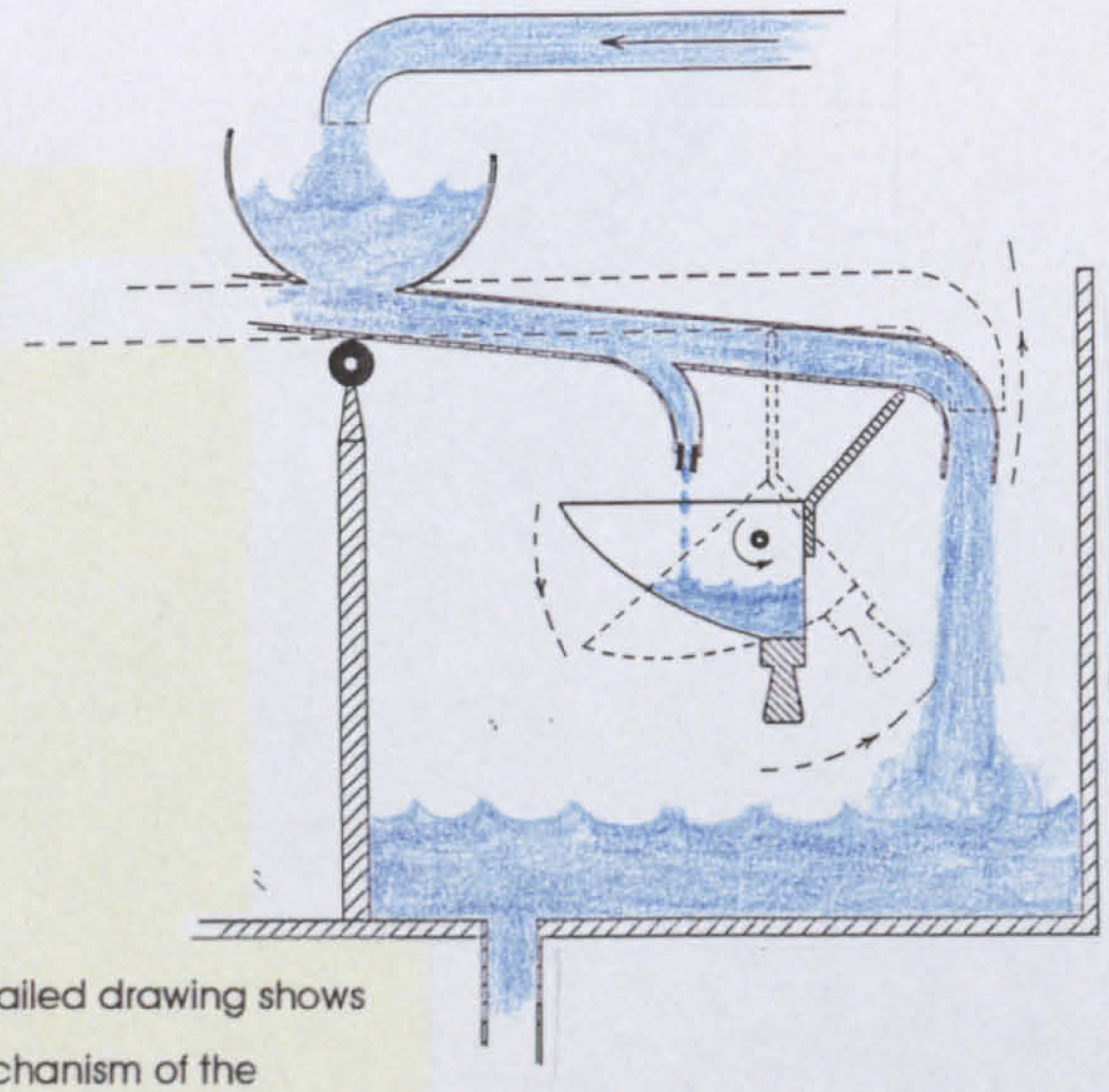


Figure (92).

Al-Hassan's reproduced drawing of fountain (2), which (as the previous model) bears the same ambiguity as that of al-Jazari.



The arrangement of the
Feeding tanks,
Fulcrum,
Balanced-pipe,
and the
Tipping bucket,



This detailed drawing shows the mechanism of the Tipping-bucket, which tilts as it is being filled and at the same time lifts up the Balance-pipe by the inclined projection on its rear causing it to tilt towards the adjacent tank. Then the counter-weight pushes back the bucket as its contents are discharged.

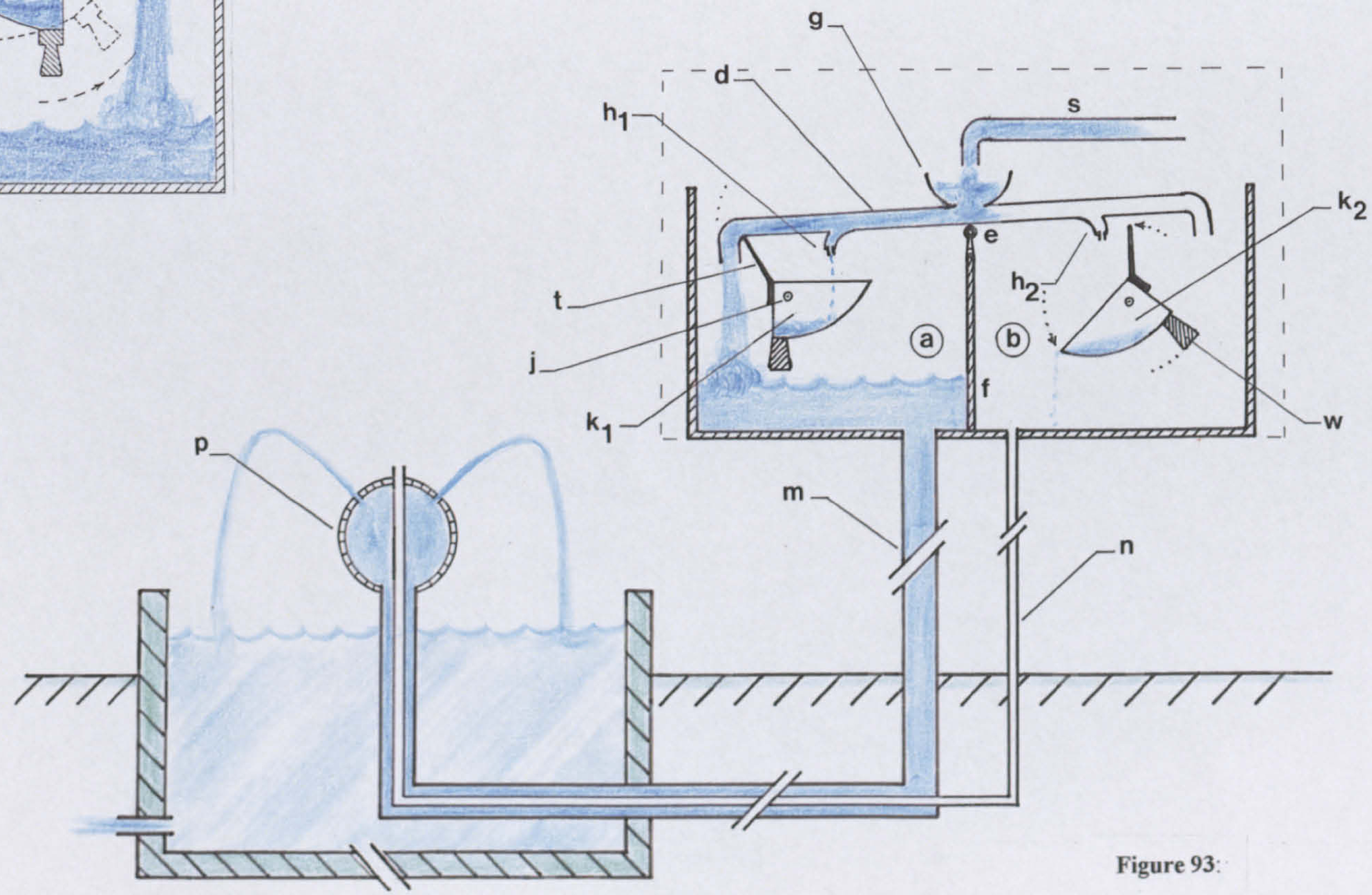
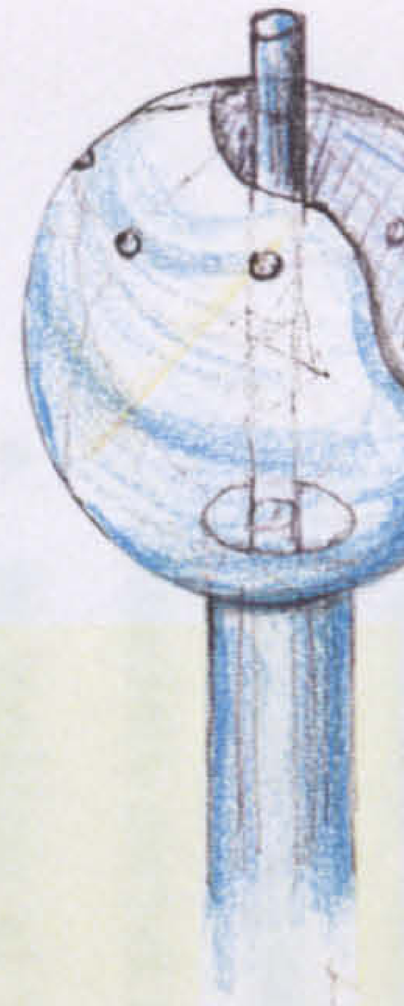


Figure 93:

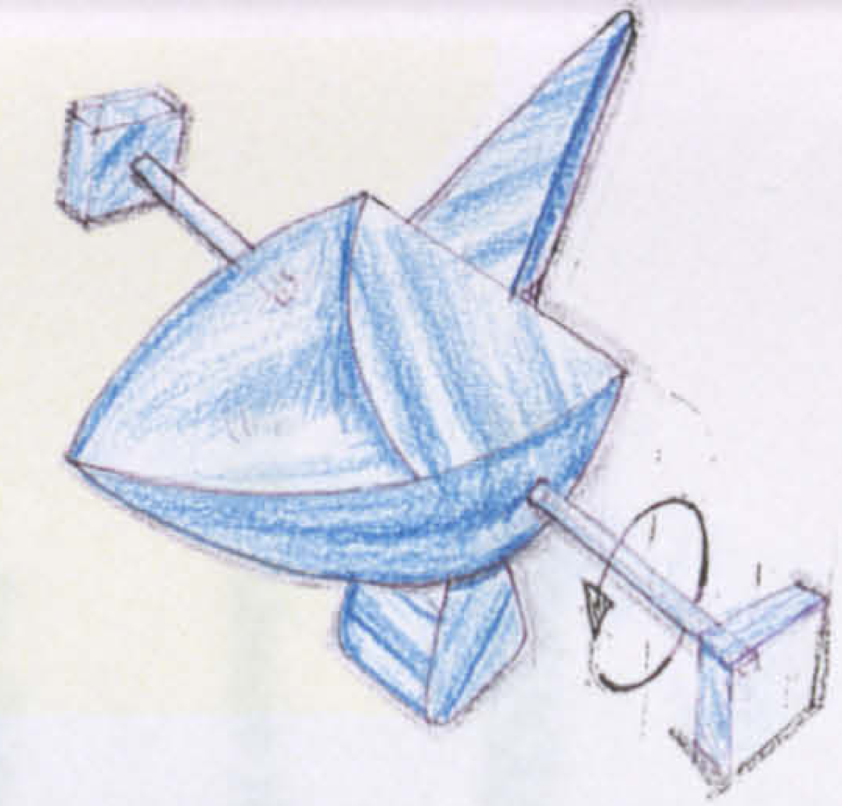
Reconstruction of the drawing of fountain (1).



Fountain-head

Form the six holes near the top centre of the sphere six arcs of water are projected, whereas the middle pipe is to produce a lance.

This drawing shows the construction of the Tipping-bucket which rotates in two pen-point bearings. The counter-weight is attached to the bottom of the bucket whereas the inclined projection is positioned on its top-end.



Pool

The size of this pool as well as its draining pipe is set in accordance with the fountain size, and the volume of the water projected.

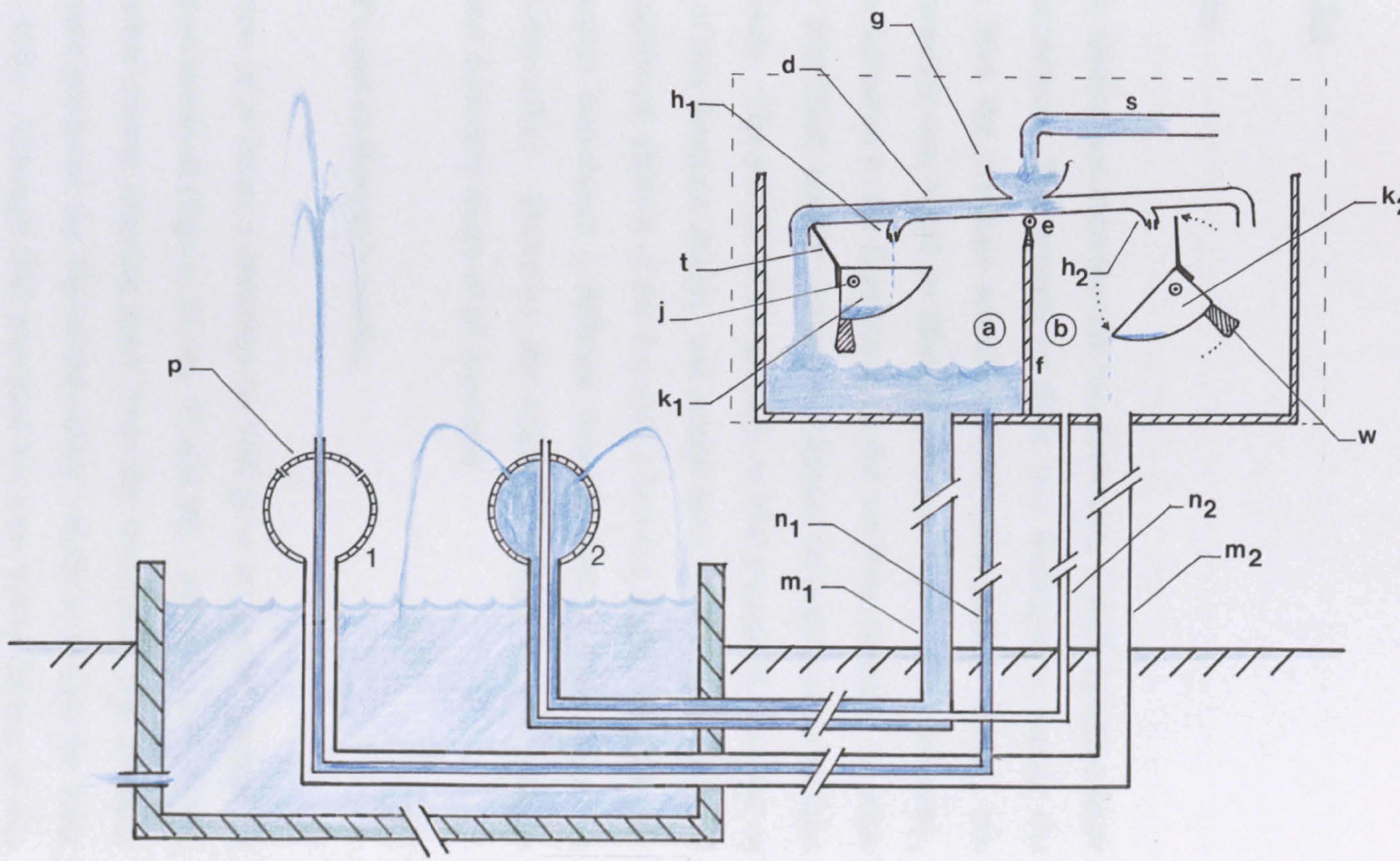


Figure 94:

Reconstruction of the drawing of fountain (2), in which the mechanism of alternation is utterly the same as in the previous model.

4. FOUNTAIN NO. 3,4

4.1. About the fountain.

As there are many similarities between the two fountains, I shall combine them in a single representation. The concept of these two fountains is exactly the same, but differs from the previous models in two main points. Firstly, the mechanism of alternation was based on **lifting-float** (see figure 101). Secondly, the water that was delivered to the fountain-head did not flow directly. In other words, a tank was first filled, and the water was released through a valve to flow into the fountain body. The profile of the ground, as Hill presumed, was one of the determinants of this fountain design, and would have necessitated the slow delivery rate and moderate altitude of the fountain's housing above the pool. Al-Jazari in this fountain introduced a different fountain-head that produces the shape of a lily-of-the-valley. However, the single jet alongside other shapes seems to be the most dominant shape of all fountains.

4.2. Discussion of Hill's and al-Hassan's works.

- The reproduction of al-Jazari's drawings by Hill gave no proper illustration of the mechanism involved (figure. 95, 96, 97 and 98). Al-Hassan, however, has given a rather clearer drawing apart from the instrument that al-Jazari described to have produced the lily-of-the-valley, which is in fact far from clear (fig. 99, 100). Although Hill provided his own interpretation of this particular instrument, no diagram was given. Figure (101, and 102) show detailed illustrations of both the fountains that I have illustrated to help the readers arrive at a full understanding.
- In looking at the construction of the float, Hill presumed that the float must have been restrained from lateral movement by a cylindrical wire cage, or something of the sort, which allowed the water to flow freely. Even though such a presumption is sound, al-Jazari would have mentioned such a

possibility since he was very precise in detailing the most important and essential parts of the devices. Therefore, a plain cylindrical cage with openings right at the bottom edge to allow the water to pass through is more likely, that being what al-Jazari had depicted and described. Having said that, we find no such similar part was made of wire in other devices by al-Jazari.

4.3. Construction of the device.

The machines of both fountains are similar. The only difference is that the second fountain was just an elaborate version of the first one. The device consists of four main components. The following description is to be read in conjunction with Fig. (101, 102).

a. Feeding tanks:

   Some distance away from the pool, a machine-house or box is built in which a tank is constructed and divided into two tanks (a, b). An axle (f) is fixed on top of the partition between the two tanks with two bearings fitted to its end (e). A ground-valve (v1, v2) is placed near the wall of the float's cage at the bottom of each tank.

b. Delivery pipes:

   Fountain No. (1): A wide pipe (m) descends from the bottom of tank (a) where it terminates at bottom of sphere (o) at the fountain-head. A narrow pipe (n) descends from the adjacent tank (b) down to where it meets the other pipe, and piecing it and terminating at the fountain-head above the sphere.

   In the case of fountain (2), al-Jazari gave rather peculiar piping. Wide pipes (m, n), are divided into two sections vertically along its entire length, and are attached to the ground-valve of each tank. One section of pipe (m) is linked to the wide vertical pipe of the head of fountain (2) and the other section is linked to the narrow vertical pipe of the head of fountain (1). The same setting with the other pipe (n) is arranged, in exchange. In the drawing

I have provided, a modification of the pipe arrangement that allows readers to follow the passageway of water (fig. 101).

c. Balanced-pipe:

Across the two tanks on the central axle (f) a short cylinder (z) with closed ends in which a ball of lead moves freely is arranged. To the top edge of this cylinder (z), pipe (d) with bent ends is attached. This cylinder is oscillating on a central axis, which is fitted to the bearing (e), working like the arm of balance. In the centre of this pipe, funnel (c) is fixed into which the supply channel (s) discharges the water. To each end of the pipe, an extension (t) shaped like a segment of a circle is attached. Two chains on the balanced-pipe suspend the conical-plugs (p1, p2). The ground-valves (v1, v2) are blocked as the pipe tilts towards one of the tanks.

d. Lifting-float:

Underneath each of the two extensions (t) attached to the balanced-pipe, a cylinder (g) with several openings around its lower edge is fixed, in which the floats (h1, h2) with a knob in their centre are placed in line with the curve of each extension.

4.4. Construction of the fountain-head.

The principle for producing the lily-of-the-valley was not clear in al-Jazari's text. The arrangement was apparently as follows: the wide pipe of the fountain-head is fixed to a vessel shaped like the 'citron' with an orifice shaped like the top of a vase. The narrow pipe, which passes through the wider pipe, terminates a little above the orifice of the vessel around which a plate shaped like the orifice of the vessel (w) is fitted. In the case of Fountain (2) (the doubled version) two similar fountains may be erected in a single pool or each one centred in a separate pool.

4.5. How the fountain operates.

Fountain (1): Water runs from supply-channel (s) into the funnel (c), then through balanced-delivery pipe (d) into tank (b) in which the ground-plug (v2) is closed. Water fills up tank (b) and consequently the float (h2) rises. As the tank is being filled with an adequate amount of water, the float then would lift up the balanced-pipe as its knob hits the curved extension, causing the pipe to tilt towards the other tank. The leadball inside the cylinder (z) rolls down towards the other end, which reinforces the swinging of the balanced-pipe, and at the same time unplugging the valve (v2). As the water is released from tank (b), it descends through pipe (n) up to the fountain-head to shoot up in a single jet. This session would last for the same period that it takes the other tank to be filled up, where the process is repeated. Then water is released from tank (a) and the fountain emits a lily-of-the-valley shape as pipe (m) deposits the water into the vessel at the fountain-head. The changeover of the fountain's shape is repeated continuously, as the device is set in motion.

Fountain (2). The mechanism is by all means the same except that the emissions are doubled, since there are two fountains. Each fountain emits a different shape at the same time as water is released from one tank. So one of the two fountains shoots up a single jet while the other produces the shape of the lily-of-the-valley. The alternation occurs as water is released from the other tank. Then the fountain that produced a single jet changes to produce lily-of-the-valley and vice versa.

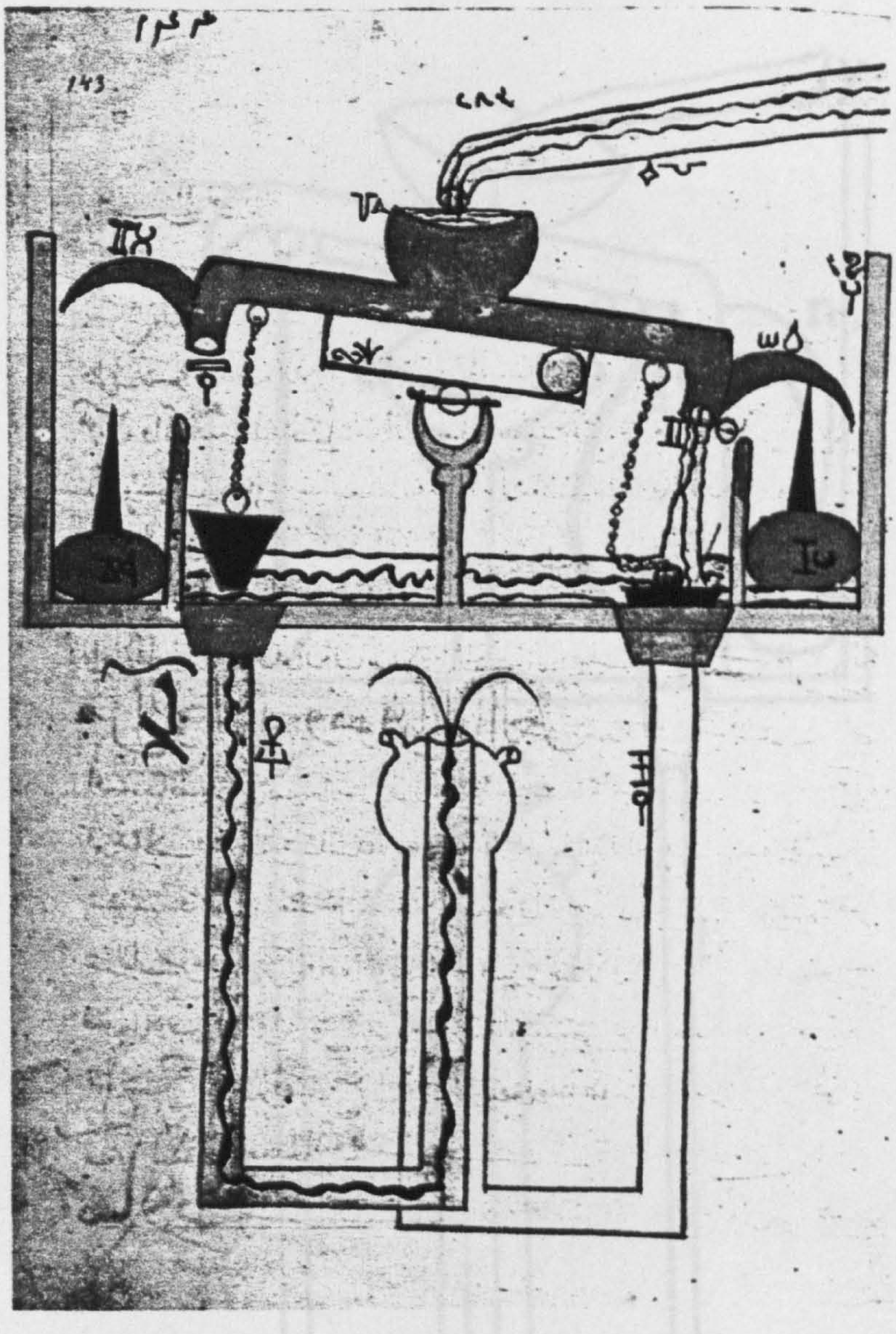


Figure (95)

The drawing of fountain (3) by al-Jazari. (Reproduced from facsimile of Istanbul, Topqapo Serai's manuscript No. 3472. by Kulture Bakanligi, 1990)

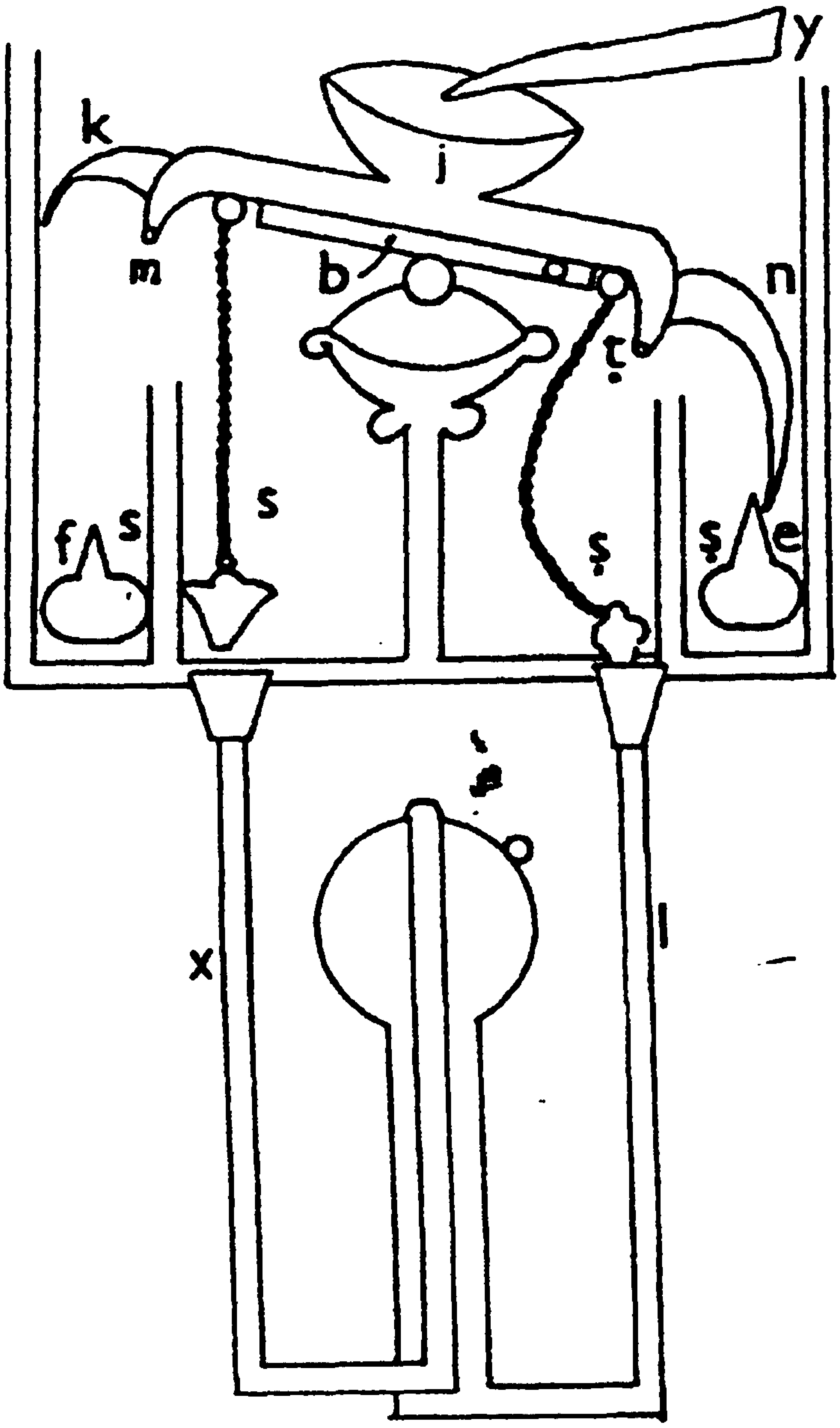


Figure (96).

The reproduction of the drawing of fountain (3) by Hill.

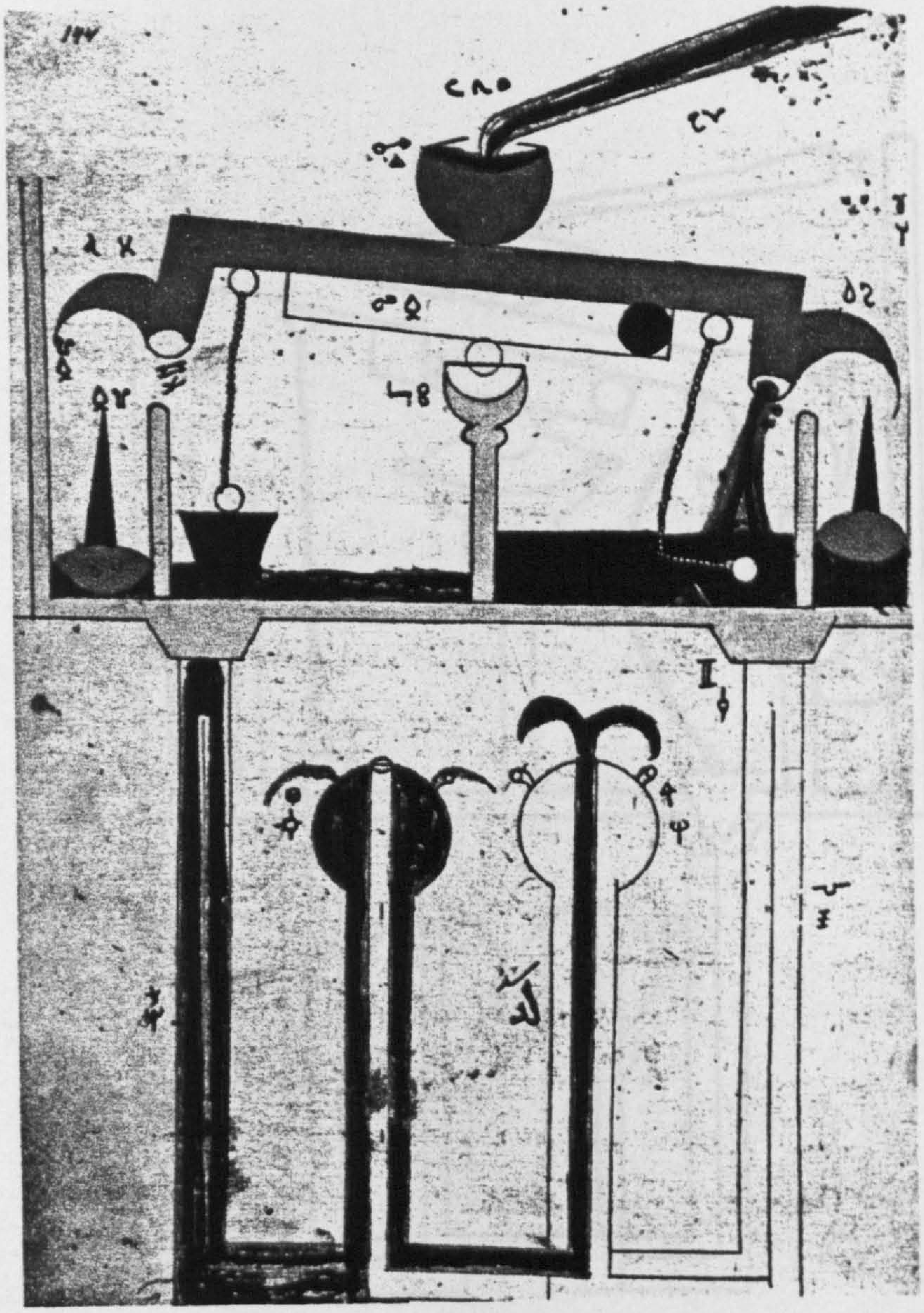


Figure (97)

The drawing of fountain (4) by al-Jazari. (Reproduced from facsimile of Istanbul, Topqapo Serai's manuscript No. 3472. by Kulture Bakanligi, 1990)

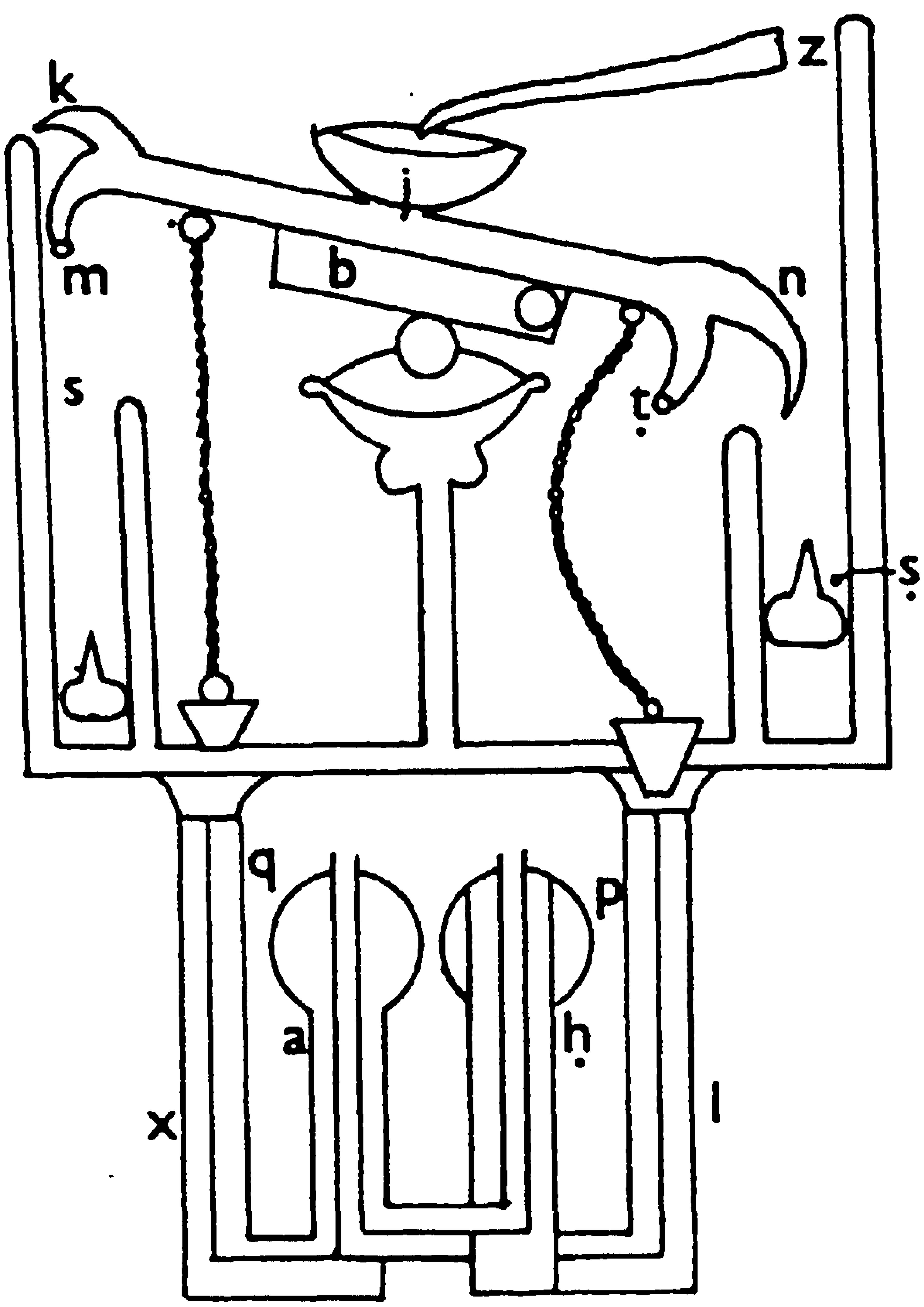
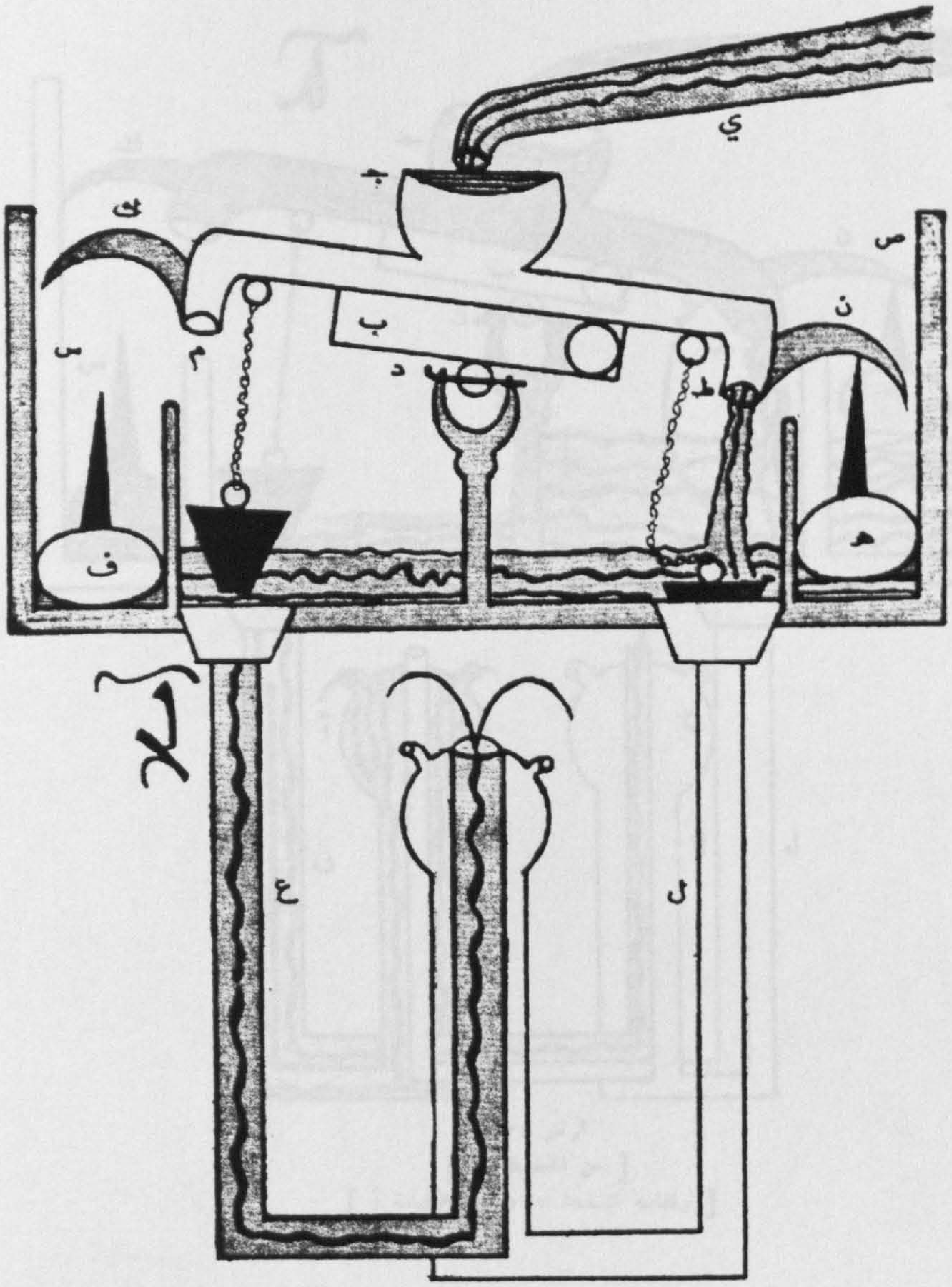


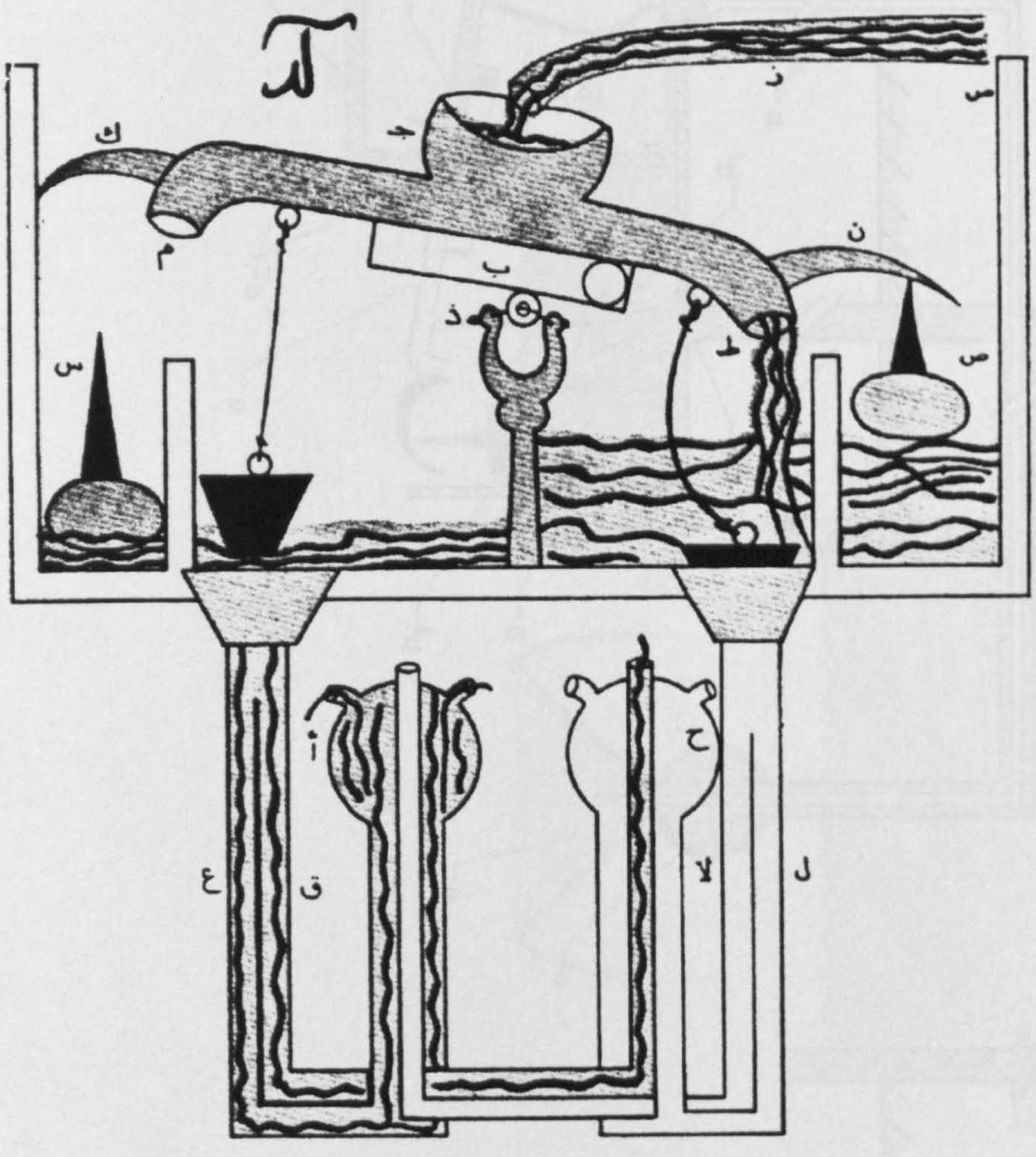
Figure (98)

The reproduction of the drawing of fountain (4) by Hill.



الرسم ١٢٣
[عن الصفحة ٢٨٣ من المخطوطة أ]

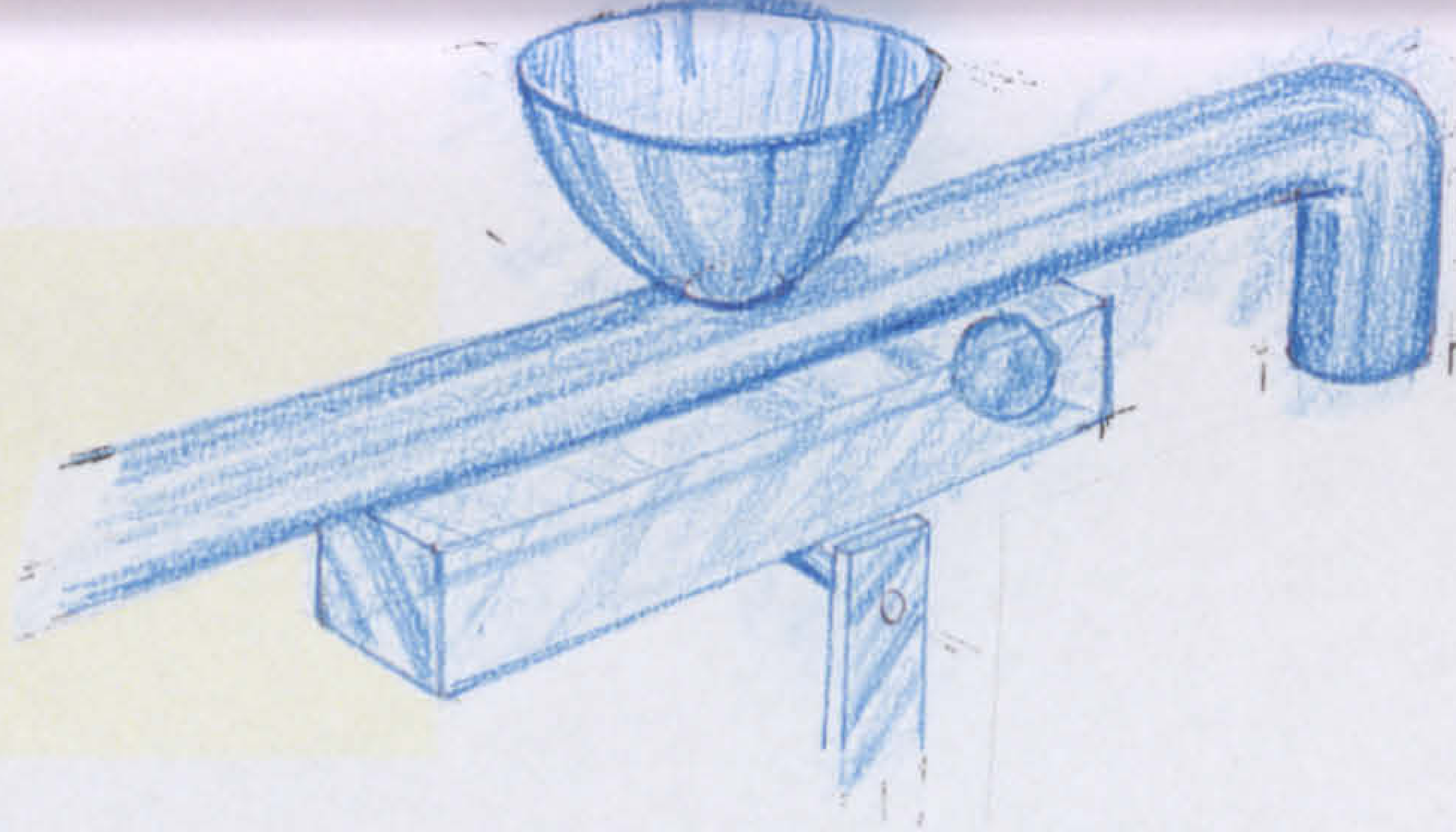
Figure (99)
The reproduction of the drawing of fountain (3) by al-Hassan.



الرسم ١٢٤
[عن المخطوطة ط]
[وتقابله الصفحة ٢٨٥ من المخطوطة أ]

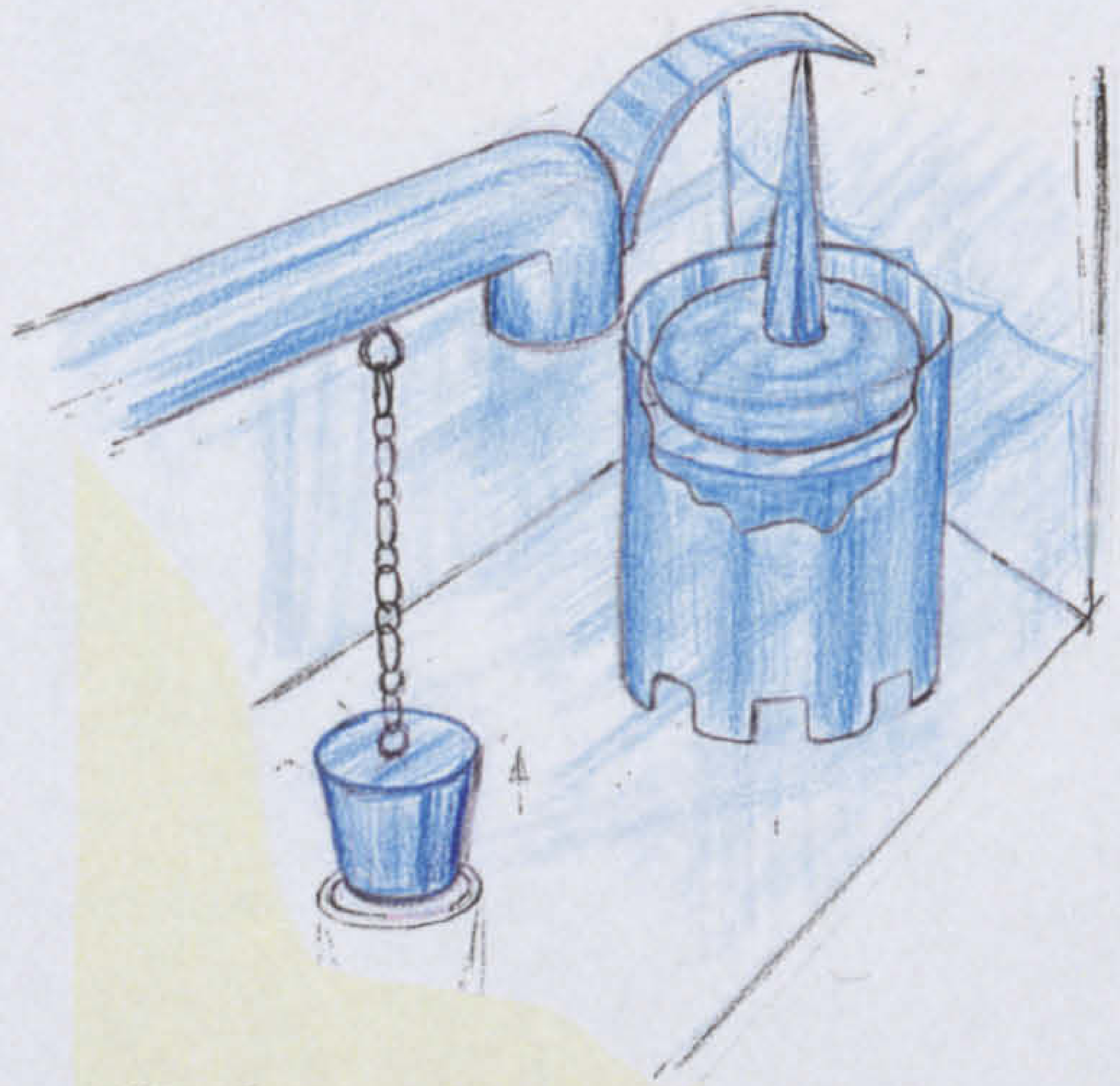
Figure (100)

The reproduction of the drawing of fountain (4) by al-Hassan.



Balanced-pipe

The short closed-ends cylinder with a lead-ball moves freely in it is set to make the oscillating movement of the balanced-pipe more efficient.



Lifting-float

The cylindrical cage with several openings around its bottom allows the water to pass through and lift up the float where its projection pushes up the balanced-pipe causing it to tilt toward the adjacent tank. The mechanism is to be repeated in the same manner at the other tank.

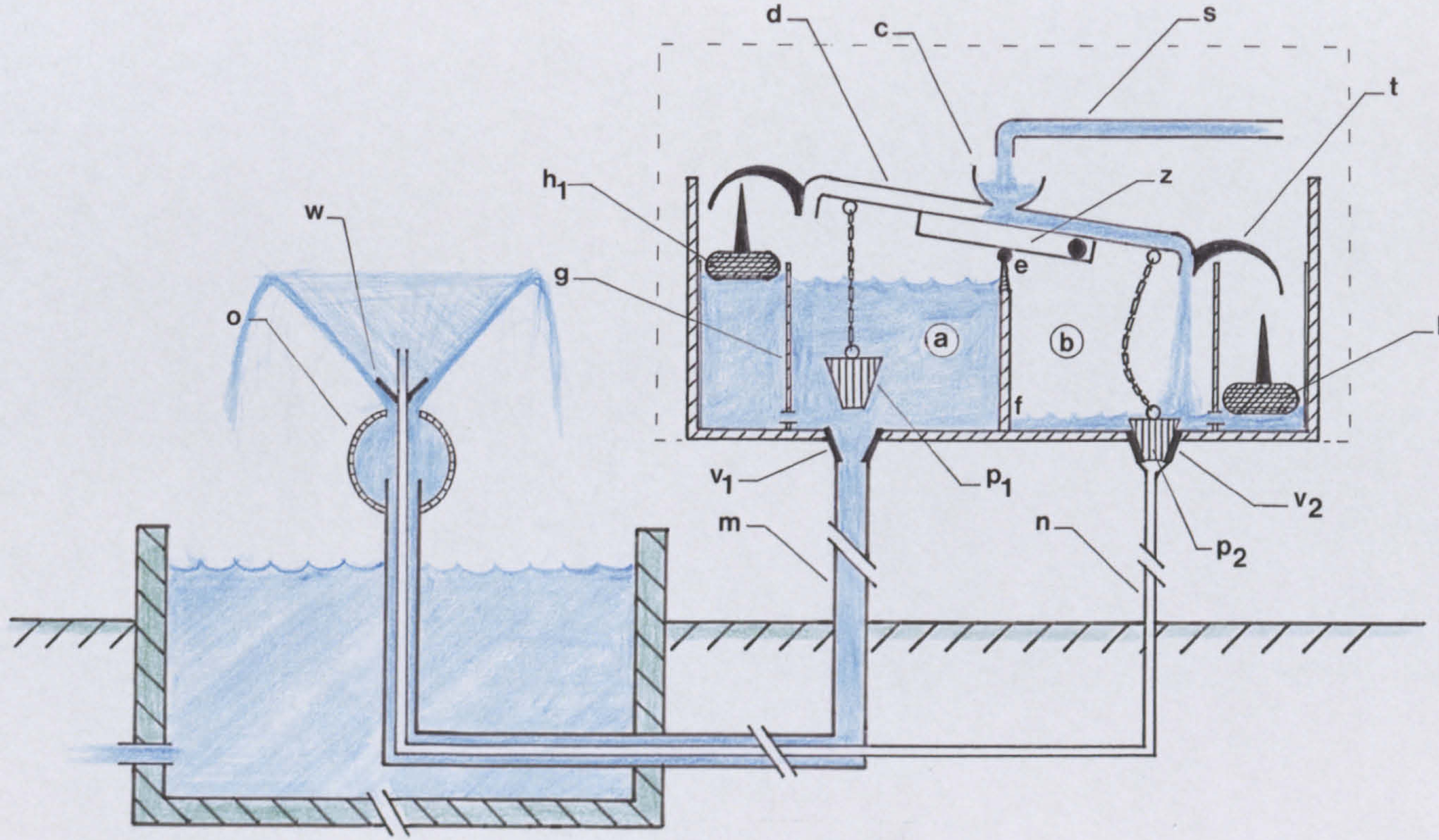
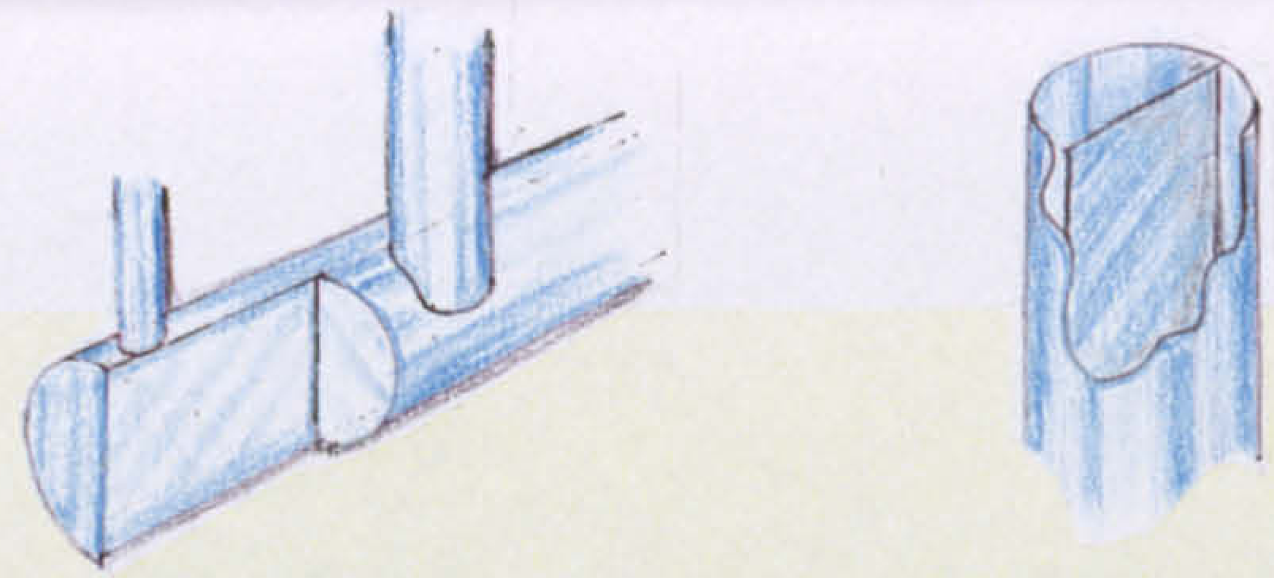


Figure 101:

Reconstruction of the drawing of fountain (3) with additional details for more clarification.



This drawings show that each one of the delivery-pipes is divided into two sections along its entire length. This is not shown in the 2D drawing provided, however the alteration is made just to make the pipe arrangement much clearer.

The water that flows out from the orifice of the sphere hits the V shape plate to produce a lily-of-the-valley shaped emission.

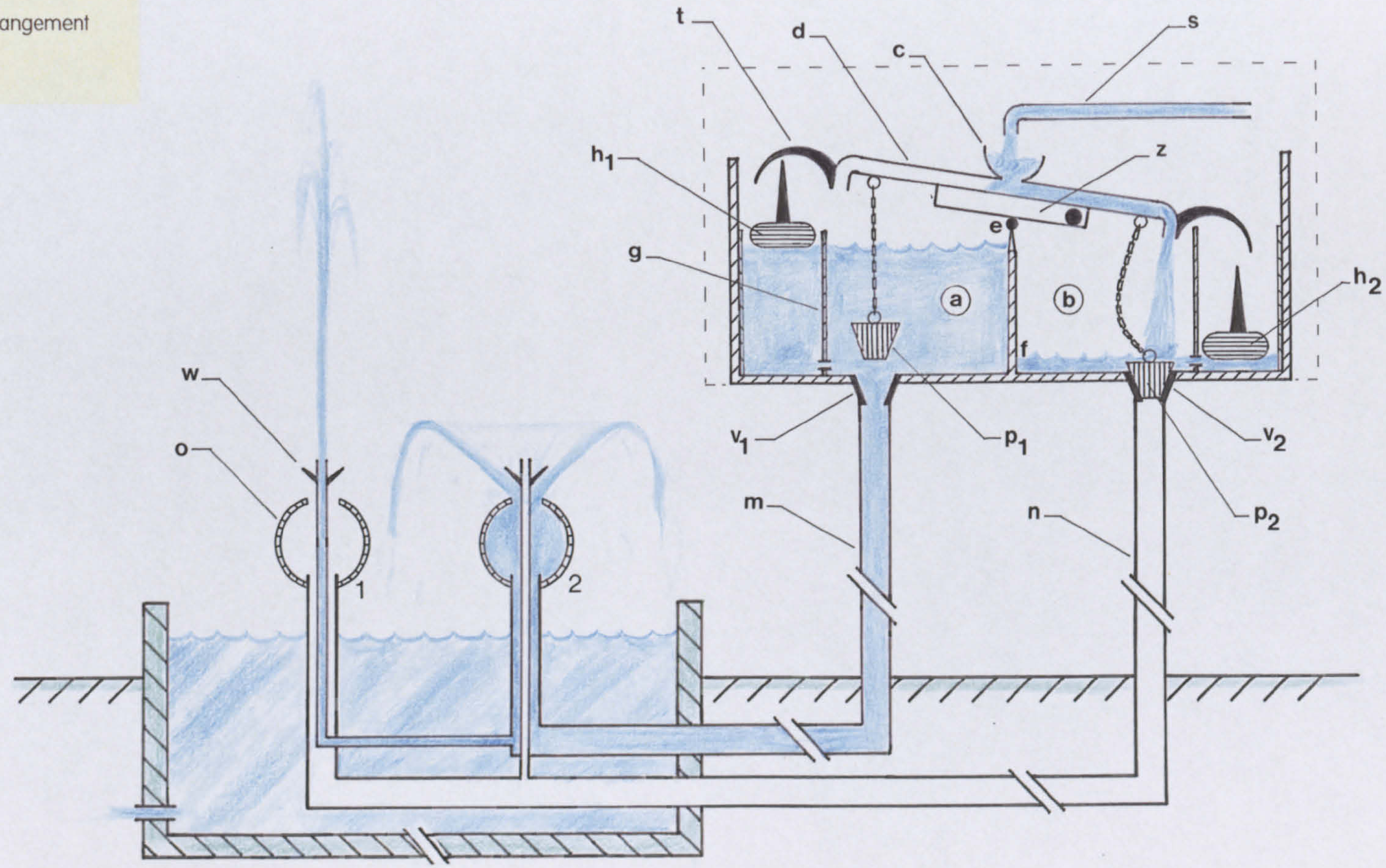


Figure 102:

The mechanism in this fountain is the same as the previous one.
Each one of the fountains (fountain-heads) can be centred in a separate pool, or both erected in the same pool as shown in this drawing.

5. FOUNTAIN NO. 5

5.1. About the fountain.

In this model al-Jazari introduced a newly developed concept of mechanism, which was based on a **tilting-bowl**. A **doubled-head central plug** is also a new concept that al-Jazari used in this particular model. The alternation of the fountain is controlled by these two concepts. A tree shape and also a tent shape were other new features of emission to be produced from the fountain-head (fig. 106).

5.2. Discussion of Hill and al-Hassan's work.

- Hill's modified drawing gave a much clearer understanding of the mechanism than the original one (fig. 103, 104); whereas al-Hassan provided a reproduction of the original drawing which is not very clear in certain details (fig. 105). But, despite this Hill showed a deep bowl and a long plug, which are practically impossible to work due to two major points. First, the deeper the bowl is, the bigger the tilting span of the tilting-bowl, so a wider square-channel is needed (see fig. 106). Secondly, the longer the plug is, the shorter the tilting span would be, which means no full discharging for the water from the bowl. In either case, the mechanism would be dead. So a great deal of care was taken by al-Jazari to balance and work out this delicate part. In figure (106) I have presented an ideogram that a shallow bowl is in fact what al-Jazari used, although it contradicts with his drawing.
- No special difficulties are posed by al-Jazari's text on this model; that made it easier to understand the mechanism. The only part that was not mentioned in the text and not even shown in the drawing, is the draining of the water that is to have been discharged from the tilting-bowl. Hill, in his explanatory notes, did not discuss this part either. Presumably, the discharged water was drained away from the fountain housing down to the drain, which already was linked

to the fountain. Most probably, this sitting was considered as common thing that is why it was not mentioned by al-Jazari and later by Hill.

5.3. Construction of the device.

a. Water-tower and the channel:

   Some distance from the pool, a house is built. In the house, a vertical tower is erected with a tank on top of it (fig. 106). This tower is perpendicular with the square channel (b) on one of its ends. Near to the other closed-end of the channel, two ground-valves (v1, v2) are arranged. On the floor of the channel, ground-valve (v2) is fitted accurately, in line with upper ground valve (v1) at the top of the channel. To the upper valve, a long pipe is fixed (c), which is higher than the altitude of the tower and the tank. On the tower, halfway down, a narrow pipe (d) is branched with an onyx on its orifice.

b. Delivery pipes:

   To the lower ground-valve (v2) a wide pipe (m) is fitted, descending all the way down to be brought up in the centre of a pool. Right above the upper valve, on the long pipe (c) a narrow pipe (n) is branched and led down to meet the other pipe, penetrating it and terminating at the fountain-head.

c. Tilting-bowl and the balanced-arm:

   A shallow bowl (j) is made, and placed under the bleeding pipe (d). Its top is closed with a plate. This cover plate is shaped with a slight concavity and a small hole in its centre. To the rim of the bowl, a ring is fitted, where it is suspended to a staple on the long pipe (c). In line with this ring, another ring is fitted on the cover plate. Beneath this ring on the edge of the bowl a small pipe (h) with an onyx is attached. Above this bowl and higher than the long pipe is a cylinder (w) with closed ends in which a lead ball is placed. Close to the end, the cylinder is pivoted. An extension is added to this end on which a long chain (t1) is joined passing through the long pipe (c) and holding the central-plug (p)- which is located between the two valves- from its upper end. On the other end of the balance-arm (the cylinder) a ring is attached, from which, down to the ring on the cover of the bowl a chain (t2) is connected. An extra weight, a lead ball (y) with a small chain, is suspended on the opposite end of the cylinder.

5.4. Construction of the fountain-head.

A vessel shaped like the 'citron' (g) with wide orifice is connected to the wide pipe (m) that was brought up in the centre of the pool. The narrow pipe (n) which was inserted into the wide pipe is passed through the fountain-head (the vessel) and raised slightly above its orifice. A convex disc is fitted to the narrow pipe leaving a slight gap between the orifice of the vessel and the concavity of the disc, which was designed to produce a shield shape. On the top end of the narrow pipe (n) a fitting similar to the 'rose' that is fitted to watering-cans and garden hoses, except with a larger hole in the centre, is positioned. This sort of fitting produced the shape of a tree by numerous tiny jets. In the middle, a single thick jet shoots up.

5.5. How the fountain operates.

Water flows into the tank filling the tower (a) from which water drips through the onyx of pipe (d) on to the cover of the bowl (j), and the water is collected inside it through its hole. Meanwhile, water flows from the tower through the upper valve (v1) as the lower valve (v2) is closed. Water rises above the valve and then descends through the narrow pipe (n) terminating at the fountain-head to produce the shape of a tree and a vertical jet. Soon the tilting-bowl (j) is filled; it tilts downwards causing the balance-arm (w) to swing, pulling up the central-plug, which in turn unplugs the lower valve (v2) and plugs the upper valve (v1). Then water flows through the lower valve down into the wide pipe (m), which is fitted to the fountain-head to produce the shape of a shield as water surges through the narrow gap between the disc and the citron. The emission is to last until water is discharged from tilting-bowl (j) through its onyx (h). Then the plug and the suspended weight (y) on the balance-arm act as a counter-weight pulling up the tilting-bowl to position, at the same time unplugging the upper valve and pluging the lower one. The interval is repeated perpetually as water flows into the tank.

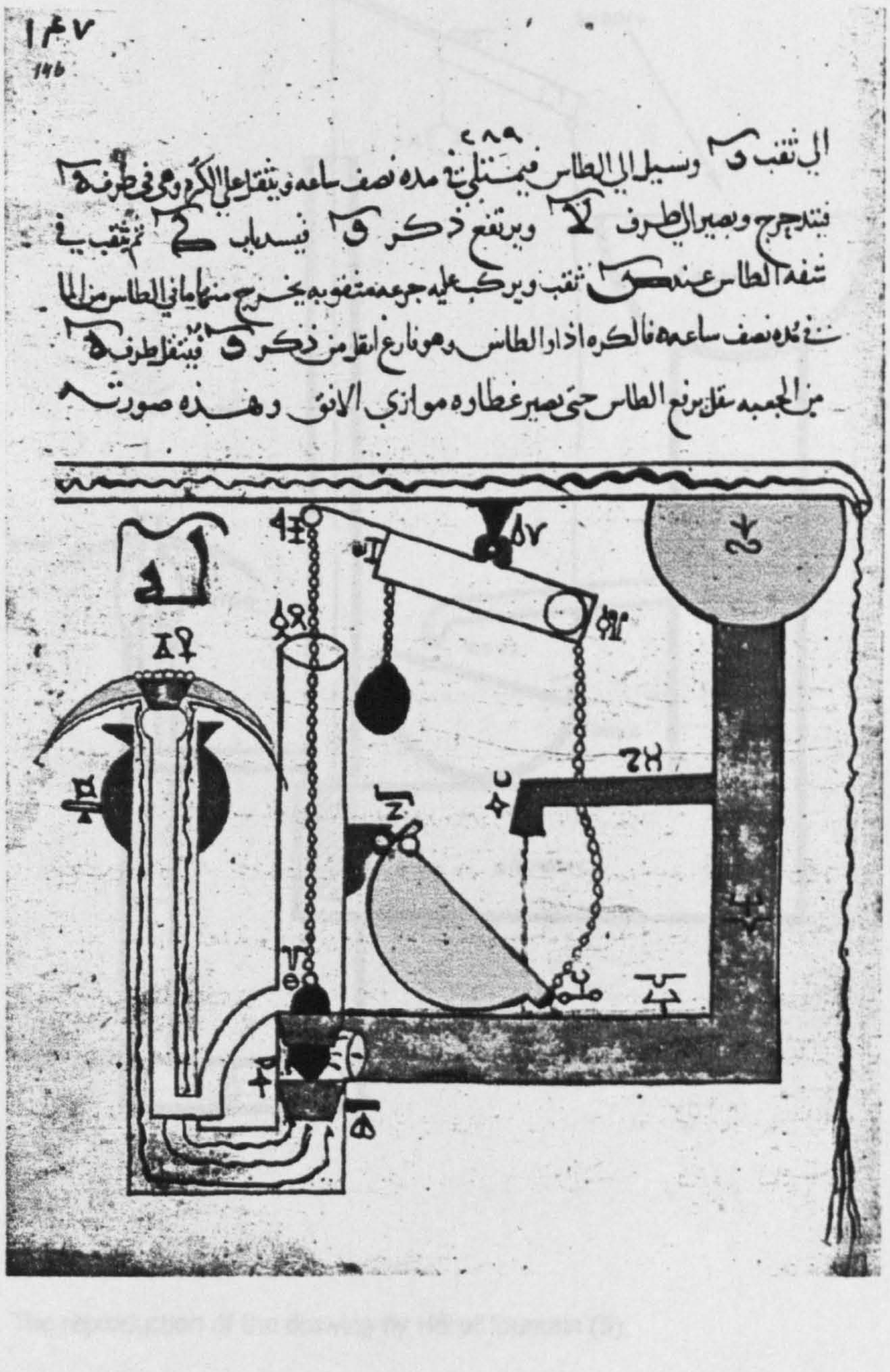


Figure (103)

The drawing of fountain (5) by al-Jazari. (Reproduced from facsimile of Istanbul, Topqapo Serai's manuscript No. 3472. by Kulture Bakanligi, 1990)

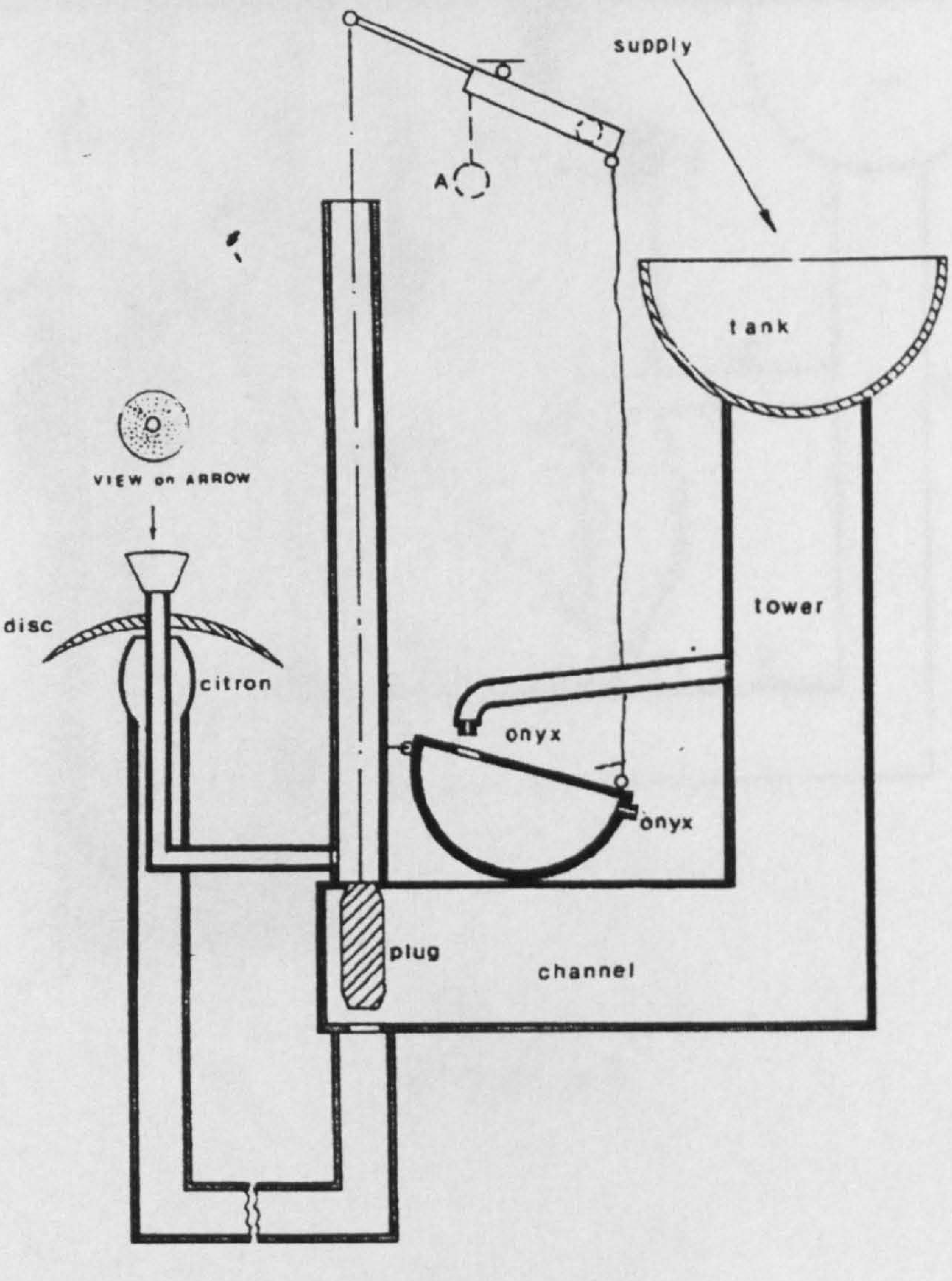
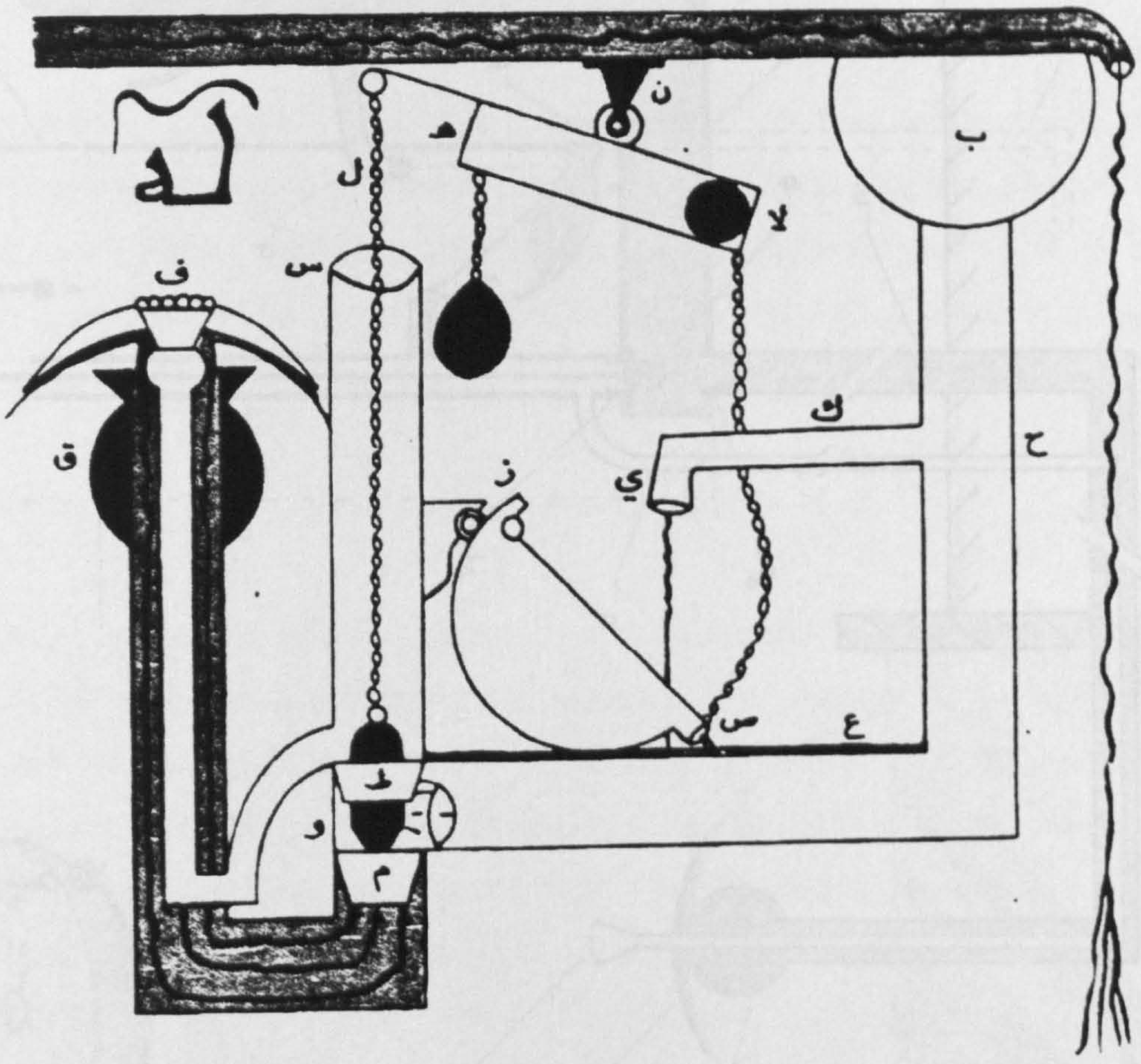


Figure (104). The reproduction of the drawing by Hill of fountain (5).



الرسم ١٢٦
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Figure (105). The reproduction of the drawing by al-Hassan of fountain (5).

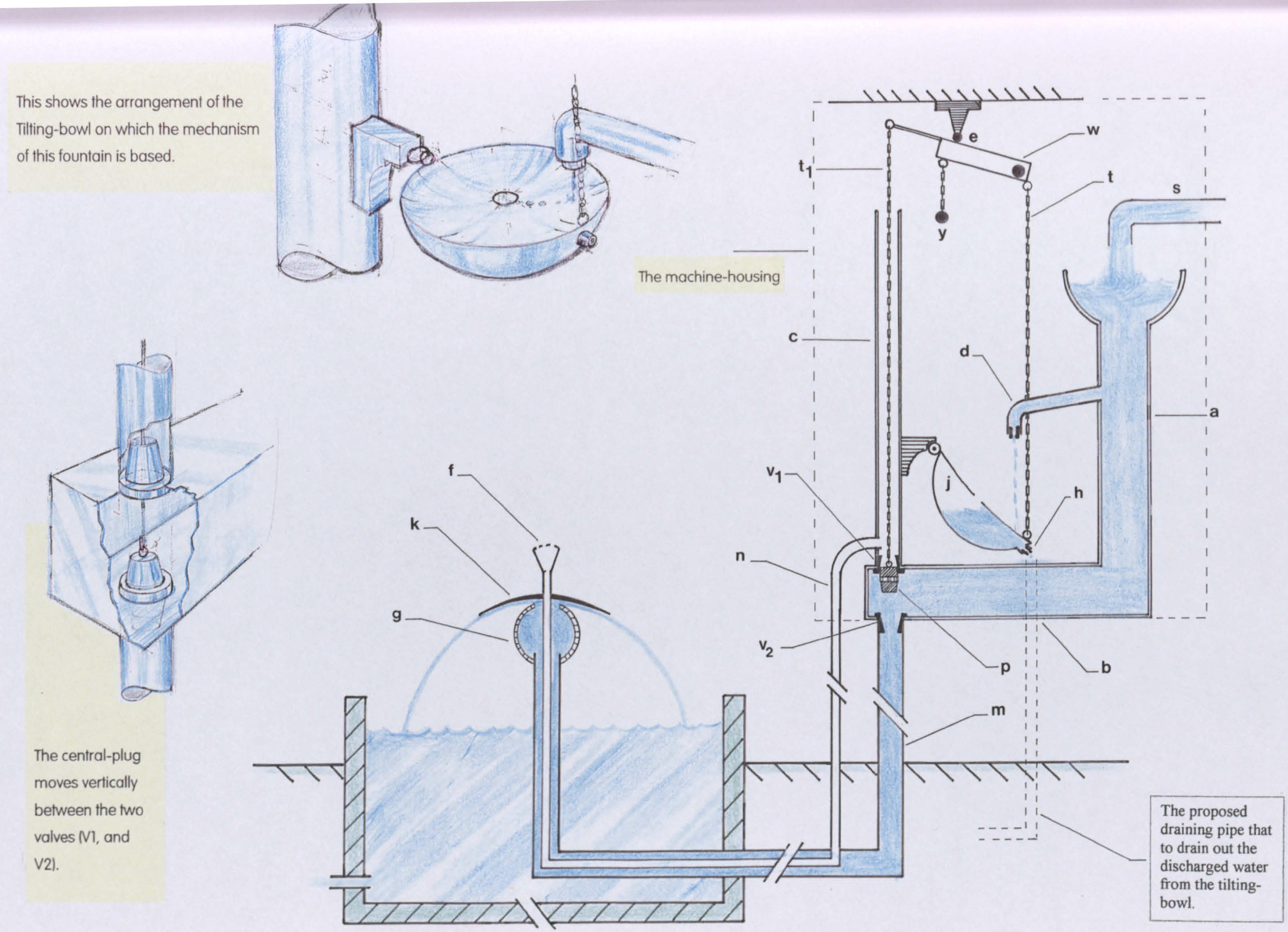


Figure 106: Reconstruction of fountain (5) with detailed illustrations.

6. FOUNTAIN NO. 6

6.1. About the fountain.

This fountain is based on the same principle as the previous one except that al-Jazari re-introduced the **tipping-bucket** concept to tilt the balanced-pipe instead of the tilting-bowl (fig. 107). This concept was used in fountains 1, 2. In this model, the fountain-head was designed to produce the shape of a tent or a shield for a period of time and then changes to a single jet for the same period.

6.2. Discussion of Hill's and al-Hassan's works.

- Hill provided no modified drawing on this fountain. Since he regarded this model as a similar version to the previous one, presumably, he seemed to direct the reader's attention to the drawing of model 5 to acquire a full understanding of the mechanism involved, despite the fact that the concept of the tilting-bucket has not been clarified. The reproduction of the drawing with Latin lettering by Hill did not give much help in visualising the mechanical process of the device (fig. 108). Furthermore, the missing part from the drawing, which is the supply channel, even made it far from clear. Al-Hassan on the other hand, gave a better reproduction of the drawing, although still relatively little assistance was afford towards comprehension of the mechanism (fig. 109). Most importantly, the misleading parts in the text of Hill as well as in al-Hassan's text, by no means comply with the drawings.
- Al-Jazari did not mention in the text nor even showed in the drawing the draining of the water that was to have discharged from the tipping-bucket. Also Hill in his explanatory notes did not discuss this. Presumably, as with the previous model, the discharged water was drained away down to the drain, which was already linked to the fountain.
- Since Hill did not discuss the mechanism of the tipping-bucket here, I have clarified this in detail in the first fountain; therefore, readers may refer to it.

6.3. Construction of the device.

a. Water tower and channel:

Some distance from the pool, a fountain housing is built. In the housing, a vertical tower (a) is erected with a tank on top of it (fig. 110). This tower is perpendicular with a square-channel (b) on one of its closed ends. Near to the other end of the channel, two-ground valves (v1, v2) are arranged; the ground-valve (v2) is fitted accurately, in line with an upper ground valve at the top of the channel. To the upper valve a long pipe (c) is fixed, which is higher than the altitude of the tower and the tank.

b. Delivery pipes:

To the lower ground-valve (v2) the wide pipe (m) is fitted descending all the way down to be brought up in a centre of a pool. Right above the upper-valve (v1), on the long pipe (c) a narrow pipe (n) is branched and led down to meet the other pipe penetrating it and terminating at the fountain-head.

c. Tipping-bucket:

Two tipping-buckets (t1, t2) shaped like half-boats with an axis close to its rear end rotate on two bearings (e), which are fixed to the walls of the device's house. The setting of the two tilting-bucket is different from that in models 1, 2. The rear ends of both tanks are facing each other. Each bucket is located beneath one side of the balanced-pipe into which the onyx tips water. An inclined projection (acute angle) is attached the vertical rear end wall of each bucket, where the top end of each meets the balanced-delivery pipe (d) as it is being tilted to its side. To the bottom of the bucket, an adequate counter-weight is fitted that to tilt back the bucket after it has poured out its contents (fig. 110).

d. The balanced-pipe:

On the central axle (f) that is erected on the horizontal channel, a short cylinder with closed ends is made in which a ball of lead moves freely. A narrow pipe (d) with bent ends is attached to the upper edge of the cylinder. This cylinder is oscillating on a cross axis, which is fitted to the bearing (e), working like the arm of balance. On the centre of this pipe, a funnel is fixed into which the suspended-funnel (y) tips. A rod-extension to one side of the pipe (d) is attached from which a long chain (o) is passed through the vertical pipe (c). This chain holds on its other end the central-plug (p) that is located between the two valves.

e. Supply channel:

The arrangement of the water flow in this fountain is different from other models. A narrow pipe (h) is branched from the supply channel (s) that is to deposit water into the suspended-funnel (y). This funnel is suspended on the topwall of the device's house from which water tips into the funnel of the balanced-pipe through an onyx.

6.4. Construction of the fountain-head.

A vessel (g) shaped like the 'citron' with wide orifice is connected to the wide pipe (m) that was brought up in the centre of the pool. The narrow pipe (n), which was inserted into the wide pipe, is passed through the fountain-head (the vessel) and raised short above its orifice to produce a single jet. A convex disc (k) is fitted to the narrow pipe leaving a slight gap between the orifice of the vessel and the concavity of the disc, which is designed to produce a shield's shape.

6.5. How the fountain operates.

Water flows into the tank filling the tower then it passes into the channel through the lower ground-valve (v2), as it is being open. Through this valve, water flows into the wide pipe (m), which is fitted to the fountain-head to produce the shape of a shield as water surges through the narrow gap between the disc and the citron. Meanwhile, water flows through the narrow pipe (h) into the suspended funnel (y). Through the onyx (the bleeder) of this funnel, water drips into the funnel of the balanced-pipe and from these into the tilting-bucket (t2). The emission of the shield continues until the bucket is filled. Then the bucket (t2) tilts down, discharging its contents. At the same time the projection on the rear of the bucket lifts up the balanced-pipe, causing it tilts towards the other side. Then the central-plug descends, releasing the water to pass through the upper valve (v1) and closing the lower ground-valve. Water released through the upper valve inflows into the narrow pipe (n) along the way down, and up again to the fountain-head to produce a single jet. This emission lasts for the same period as the shield, until the other bucket is filled, and the process is repeated perpetually.

Figure (107)

The drawing of fountain (6) by al-Jazari. (Reproduced from facsimile of Istanbul, Topqapo Serai's manuscript No. 3472. by Kulture Bakanligi, 1990)

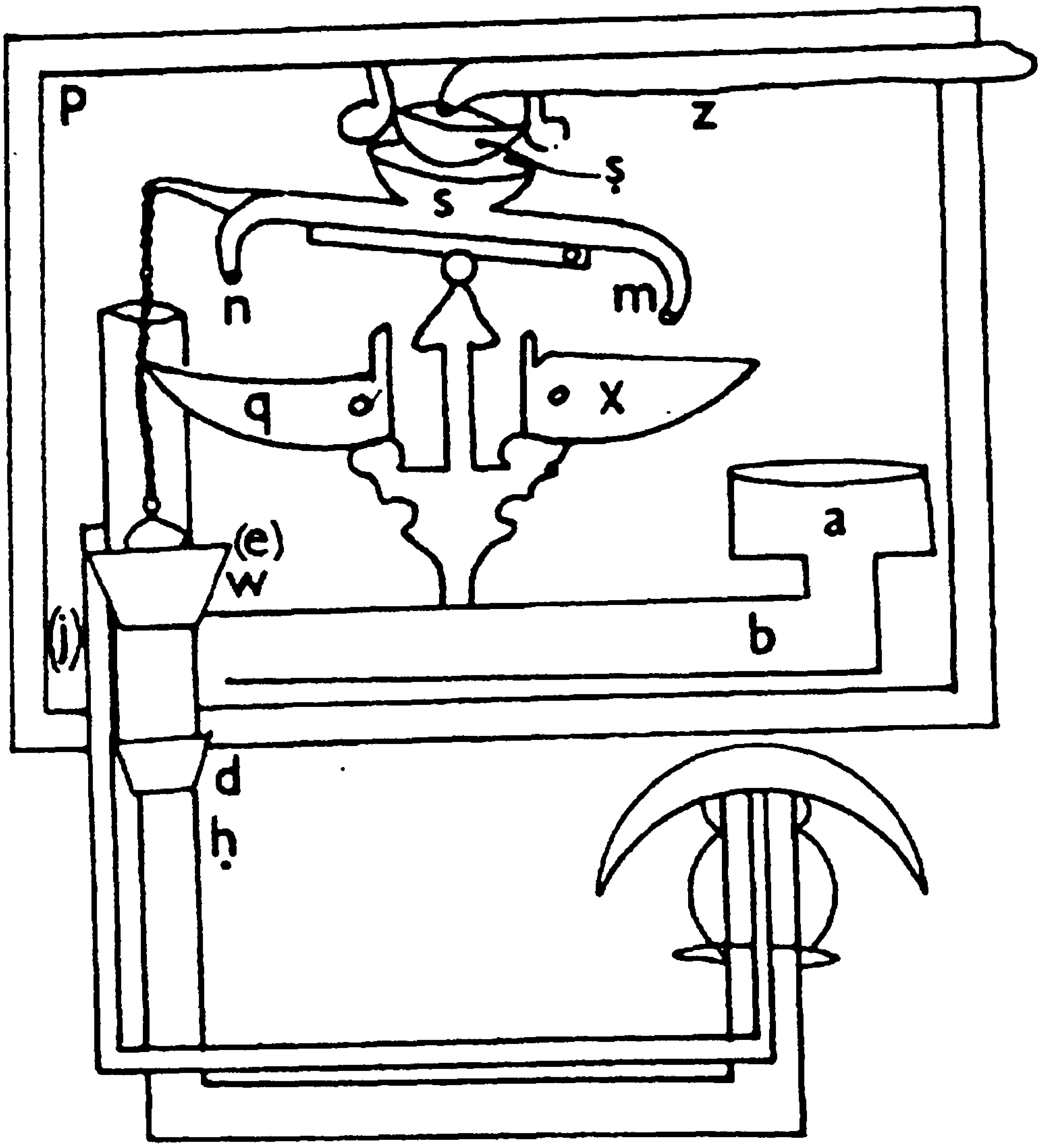
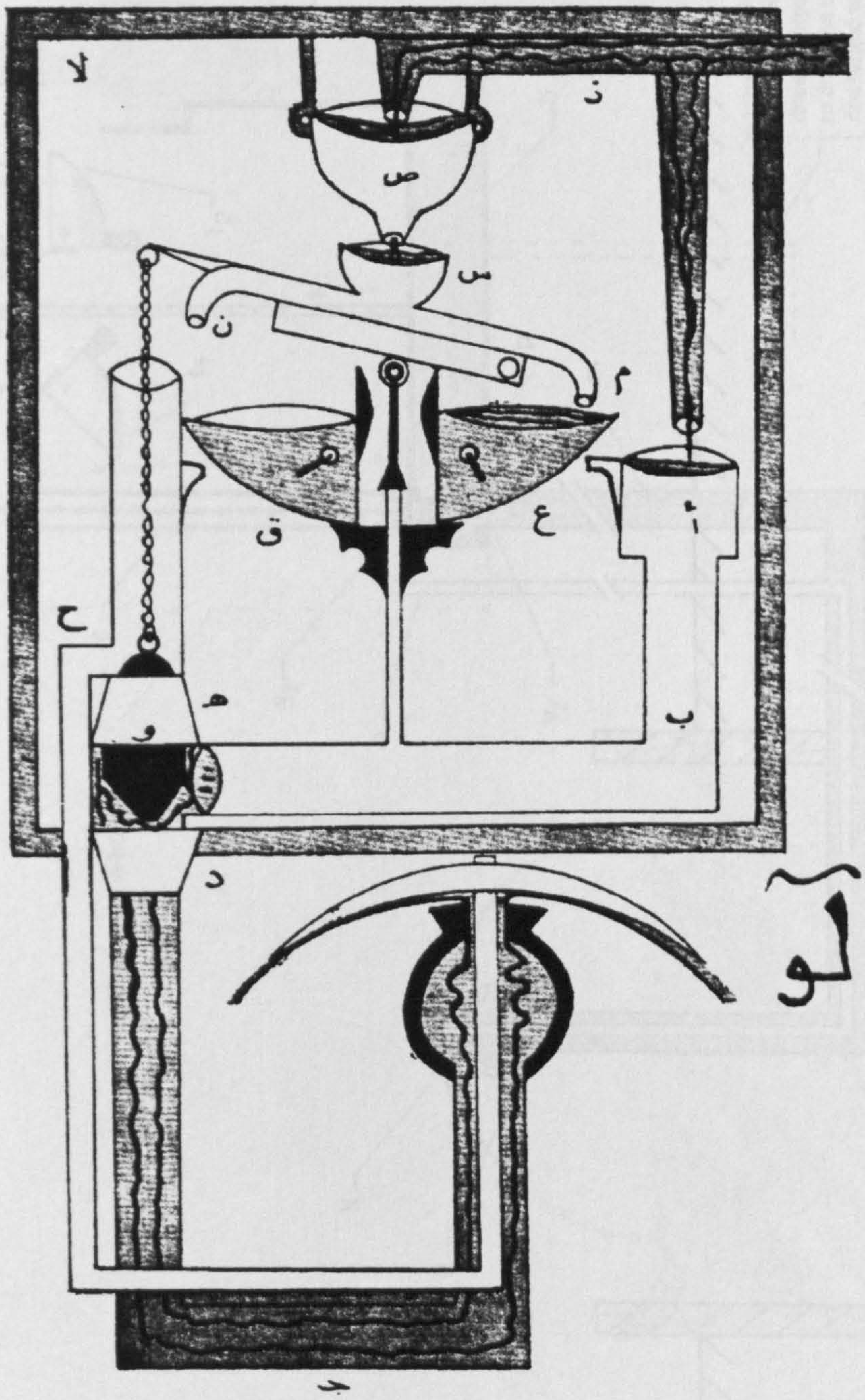


Figure (108)

Reproduction of the drawing from the Oxford manuscript by Hill which is completely obscure.



الرسم ١٢٩
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Figure (109)

Reproduction of al-Jazari's drawing by al-Hassan, which bears the same ambiguity, particularly in the mechanism of the tipping-bucket.

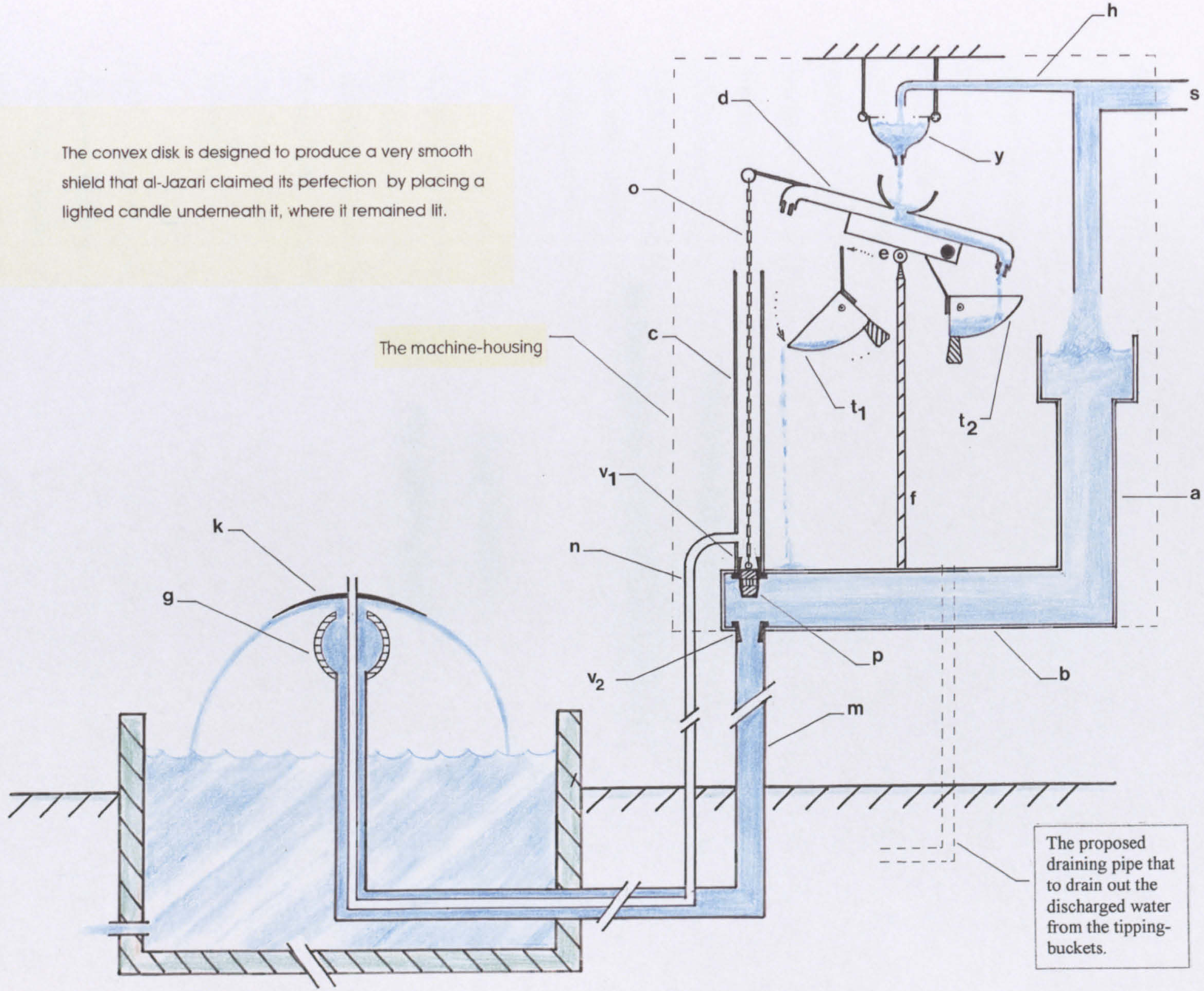

Figure 110:

Reconstruction of the fountain in which al-Jazari used the mechanism that based on the tipping-bucket that attached to a central-plug as in the previous model.

The Fountain Design

In the Works of the Third Engineer

Taqi al-Din

(The sixteenth century)

1. The Engineer and his Book

The tradition of Islamic engineering came to an end after the last known inventor called Taqi al-Din (*Taqi al-Din Mohammed Bin Maarouf al-Dimashqi*) (1520-1585). His scientific status was highly respected among historians. Biographers, on the other hand, regarded his family origin as controversial. The historian Mohammed A. Dhman (1985) objects to the claim that *Taqi al-Din* was of Arabic origin; he affirms an assertion on this issue that in a treatise[1] of *Taqi al-Din* an account about himself is introduced, in which his family origin can be traced. *Taqi al-Din* concludes this treatise by saying 'Written by the mercy seeker of the Merciful *Taqi al-Din Mohammed Bin* (....)[2] *Bin Khemartakyn*. The term *Khemartakyn* listed in his descent, Dhman says, indicates that he is of a Turkish origin as this term is one of the Turkish common names. Nevertheless, he and his grandfathers for four hundreds years have been known as Arabists[3].

Taqi al-Din lived a prosperous life, and he was brought up in a house of knowledge; his father was a judge (as well as himself), this was the highest profession at the time. His interest in mathematics, mechanics, and astronomy since the childhood made him a renowned scholar. He composed several books on mathematics, arithmetic, algebra, and the engineering of mechanical clocks. However, he was mostly celebrated as an astronomer as the majority of his books were on astronomy.

In the time of Suleiman the Magnificent (1520-1566), the Sultan of the Ottoman Empire, and his successor, Taqi al-Din's scientific achievements flourished and were highly blessed. But his career came to an end in 1580; the year that witnessed the astonishing moment for Taqi al-Din (head-astronomer) and his colleagues as they were taken by surprise when the destruction of the last observatory in the Islamic world took place in Istanbul. It was believed that senior theological

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[1] The Egyptian Books House , Ahmad Taymor Library, Collection department, No. 216,9.
[2] For more information on Taqi al-Din see Al-Basir Journal 1985, V. 4 (Arabic text).
[3] Dhman, Ahmad (1985) *Ilm al-Sa'at wa al-A'mel biha*. p. 87.

scholars were mistakenly certain that the observatory has been used by Taqi al-Din and his team for practising divination, which was against Islamic tradition. They took advantage of such issue and persuaded the Sultan to get rid of the observatory. Taqi al-Din died five years after this incident, leaving a significant scientific record.

As far as Taqi al-Din's engineering achievement are concerned he has left us a very important book on mechanical devices bearing the title The Splendid Methods of the Spiritual Devices *Al-Turoq al-Sanyaa Fi al-aallat al-Rohaniyaa*, which is a continuation of the tradition of Islamic mechanical engineering. Despite the fact that Taqi al-Din had followed the pattern of Banu Musa and al-Jazari, he introduced several machines of which no similar sort is described in any work of his predecessors. Most importantly, from a historical aspect, two significant points make his book substantially distinctive. Firstly, Taqi al-Din's book completes a missing link in the history of Islamic engineering. He is considered to be the last name in inventors and scholars, hence no one has succeeded him in any branch of engineering, or at least in conducting a fine scientific work on the same scale. The second important point is that this book coincides with the era of the Western Enlightenment. Taqi al-Din finished his book in 1552, which is prior to the appearance of Agricola's book in 1556. Yet in Europe Captain Agostino Ramelli did not introduce his book until 1588. These historical facts have reinforced the thought, which proclaims that a number of machines described by Taqi al-Din were earlier to the similar ones appeared in the Western references.

About this, al-Hassan writes that Taqi al-Din's description in 1552 of the steam turbine and nozzles was of great importance in the history of mechanical engineering. Although in the West, in 1629, Branaca had introduced the first description of its kind of the steam turbine, it was utterly impractical. Later on, in 1648, Wilkins described a practical version of a steam turbine. This means that Taqi al-Din has described very clearly this mechanism one hundred-years before anyone else, when the historians of technology believed that Wilkins was the first to introduce it[4].

[4] Al-Hassan, Ahmad (1987) *Taqi al-Din wal al-Handasa al-Mikanikiya al-Arabiya*. pp. 34. 35

Unfortunately, no serious work has been devoted to Taqi al-Din's book The Splendid Methods of the Spiritual Devices. The first introduction of the book and the only to the present time was in 1987, that was a monograph on Taqi al-Din for readers with knowledge of Arabic, accompanied with an offset reproduction of the original manuscript was issued by Ahmad Y. al-Hassan. Also, al-Hassan provides reconstructed drawings with explanatory notes on the four water pumps described in Taqi al-Din's treatise.

Taqi al-Din's book covers six categories of mechanical devices. The first chapter describes an astronomical mechanical-clock and another four clocks which operated by water, flame and sand. Three weight-lifting devices using gears and pulleys are listed in the second chapter. The third chapter describes three water-lifting machines (these have been investigated by al-Hassan). Four fountains and three perpetual flutes with devices that produce tinkling sounds are included in the fourth chapter. The fifth chapter deals with tricky vessels and amusement devices. The last chapter is devoted to a barbecue's skewer that rotates by itself.

As far as fountain development is concerned, my work will investigate fountain models, which are described in Taqi al-Din's book and provide a complete edited description along with technical drawing and illustrations.

The importance of this work emerges in a number of points which, in general, offer the reader with interest in Islamic engineering, as well as those who have a particular interest in fountain development, an introduction to the work of the last prominent engineer in the history of Islamic civilisation. These points are as follows.

1. The current investigation is to introduce the only English edited translation of Taqi al-Din's work, particularly on fountain design.
2. To provide a complete reconstruction of fountain models along with commentary notes and detailed illustrations.

3. To draw a line under the designing culture in Taqi al-Din's fountain, by discussing the development of the principles and concepts involved.

2. Method of investigation

Since there is no study which has been undertaken concerning the design and engineering aspects of fountain development in Taqi al-Din's work, my investigation will examine those aspects and draw a conclusion on the culture of Taqi al-Din's fountain design. The study is based on a photocopy from a microfilm of the original manuscript I have acquired from Al-Imam University No 5232/f[5]. In addition, the book issued by al-Hassan, mentioned earlier, is the second reference in this study.

Taqi al-Din describes, in the fourth chapter, four fountain devices. At the beginning of this chapter he has given a brief introduction concerning the manufacturing of four major components on which the devices mechanism were based. Firstly, **Tipping-bucket** (*al-Kifaa*); secondly, **Lifting-float** (*al-' wama*); thirdly, **Siphon** (*al-Maqlab*); and fourthly, **Balanced-pipe** (*mizab al-Ma'*). Later he describes the fifth mechanism, which is **Scale-buckets** (*al-Kifaat*). This is followed by details on the construction of three mechanical concepts to operate the fountains using the components described earlier. Then he moves on to describe four fountains, one of which is basic with no machinery, whilst the other have various mechanical devices. But his description were confined to the fountain-head and pipe arrangement, so the application of a mechanical concept for each fountain was left to the maker of the fountains.

The description in the text on the principles and the mechanical concepts creates no difficulties in understanding the mechanisms. In general, Taqi al-Din was very clear and systematic. In terms of the drawings, Taqi al-Din did provide rather unsatisfactory illustrations.

[5] The library of Al-Imam University, Riyad, Saudi Arabia (5232/film). The original manuscript is an acquisition of The Chester Beatty Library, Dublin, (MS 5332).

The tradition of designing fountains was continued in terms of the care that used to be given to dimensions and scales which was of less importance to Taqi al-Din, as we have experienced in the work of his predecessors, Banu Musa and al-Jazari. The gaps in our understanding are about some materials, which were in use at that time to manufacture certain components.

Respecting that the current investigation is not intended to discuss, specifically, any materials and measurements used, no detail will be given unless any of those components have been examined, then details will be given. We gather that Taqi al-Din was mainly concerned about presenting what he has made, regardless of any measurement or scale involved.

Therefore, the objective of this thesis is dual: (1) A reconstruction of Taqi al-Din's designs is set to represent the principles he introduced along with the mechanical concepts. (2) By doing this study will maintain with the utmost core of the nature of Taqi al-Din's work by following his method, and re-introducing each fountain individually.

3. Mechanisms and Structural Principles (components)

In order to follow Taqi al-Din's method of introducing his fountains, I shall try to give a faithful translation; modification will be introduced where necessary in order to provide a clear descriptive text. This will allow the reader to obtain an idea of the engineering culture of that period. Taqi al-Din describes three concepts by which the three alternating fountains were operated. The first concept is by using a lifting-float; the second concept is based on the idea of weight-bucket; and the last concept is by the mechanism of the tilting-bucket. He gives also a description of two main structural components, the siphon and the balanced-pipe. Here I shall combine each concept with one fountain in order not to prolong the description of each single concept and fountain individually. For, I will later on introduce the three fountains in the same way I have with the designs of Banu Musa and al-Jazari.

- Tipping-bucket (*al-Kifaa*):

This is made in the shape of half pan (*tarjahar*)- which has a shape like a boat- with two axles on either side. An inclined projection is attached to its rear end to serve the purpose of lifting up the balanced-pipe as the bucket is filled up with water and consequently tilts down pouring out its contents into a small tank underneath.

The above description is what Taqi al-Din provided. Probably, without the help of the clear description for the same component by al-Jazari, it would be rather ambiguous. Taqi al-Din was very abstract in explaining the construction of this bucket. He did not mention counter-weight which is to be attached to the bucket, and is crucially important. However, I presume that such a component was very common to the audience to whom the book was directed. See figure (113).

- Tilting-buckets (*al-Kifaat*)

Two scale-bucket are made. To the rim of each, a ring is fitted from which it is suspended by a staple on the inner wall of the main tanks. Each bucket is also held by three wires or fine chains and is attached to balanced-pipe where it is located right above a sub-tank. See figure (118).

- Lifting-float (*al-'wama*)

Like a round loaf of bread, the float is made out of fine wood that floats on the water. Alternatively, Taqi al-Din says it is possible to make it from solid colocynth covered with pitch of any sort. A vertical stick is fitted in its centre to serve the purpose of lifting up the balanced-pipe. A small tank to restrain the float is erected into which a siphon is positioned. See figure (121).

- Siphon (*al-Maqlab*)

This siphon is made of narrow copper pipe bent down into parallel short and long parts. Through a hole on the wall of the tank, the short part is inserted with its end close to the bottom of the tank. So the longer part is driven out of the tank downward to discharge the water that is being poured into the tank. Taqi al-Din drew attention to the amount of water in the tank, which must cover the siphon completely. See figure (115).

- Balanced-pipe (*Mizab al-Ma`*):

  Across two adjoining tanks and on a central axle that centred in between a balanced-pipe are fixed which rotates in two bearing. Two narrow short pipes are attached to each end of the balanced-pipe. Towards the middle of each side of the pipe, two wide short-pipes are branched. On the top of the balanced-pipe and at the middle, a funnel is fitted. This balanced-pipe is tilted towards one of the tanks as the water is deposited into the funnel, from which water runs down into the main tank and the sub-tank. See figure (118).

4. FOUNTAIN NO. (1)

4.1. About the fountain

This fountain is of a basic type, which has no mechanical device. The fountain is constructed with a double fountain-head. It is basically designed to produce the shape of a shield or tent, and three arcs in a constant emission. The key feature of the fountain's operation is the high static pressure of water. This requires appropriate sizing of the tank, which is positioned at some distance from the fountain, and above its height. Drainage is another essential element; the same as in Banu Musa and al-Jazari fountains, and is intended to maintain the perpetuity of the fountain. Therefore, the fountain is to be erected nearby a running water source such as river or spring. Figure (111) shows the original drawing by Taqi al-Din.

4.2. Construction of the fountain

- Feeding-tank:

  Above the height of the fountain-head, an appropriate sized tank (t) is located, from which a delivery pipe (m) is led down and is brought up in the centre of the basin (b) to deposit the water into the lower-head (d) of the fountain. A narrow pipe (n) is inserted through the pipe (m) and raised above pipe (m) where it is attached to the upper-head (e).
- Fountain's body:

  This is a round basin (b) raised above the ground on a conical or cylindrical base (c). The size of the basin is determined in correspondence with the fountain-head.
- Fountain-head:

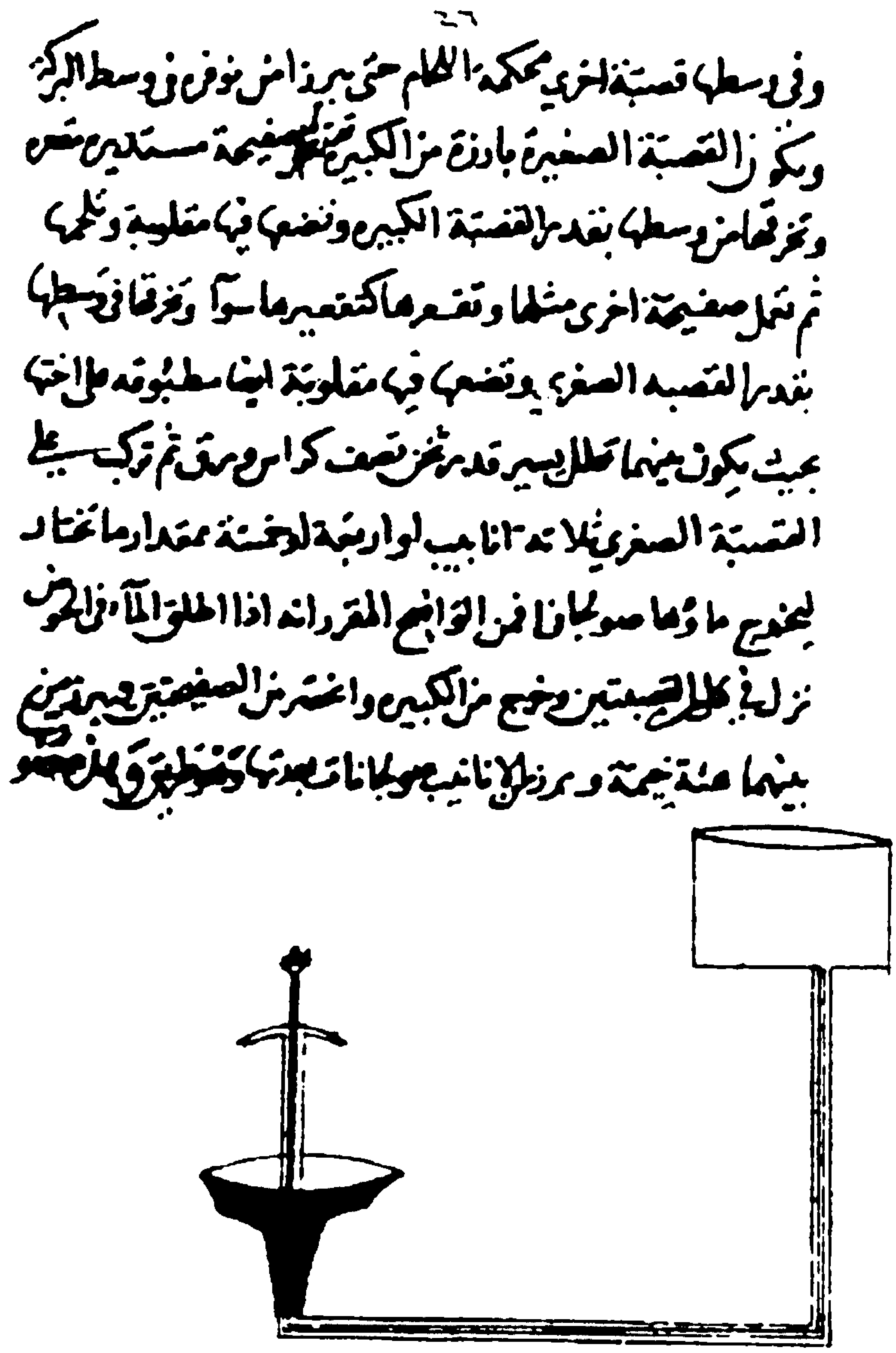
  This consists of two heads. The upper-head (e) is made of three small inclined pipes, which are branched from the end of the pipe (n). Water flows in three directions to create three arcs of water. The lower-head (d) is made of a concave disc that is soldered to the rim of pipe (m) facing downwards. Another similar disc is positioned on pipe (n) and brought close to the other disk leaving a small gap, then is soldered in position, so water flows out the gap between the two discs to create the shape of a shield.

- Drainage:

  This is an under-ground passage or a floor-channel (f) which directs the water back into the main source. The architectural setting of the fountain determines the design and the system of discharging water.

4.4. How the fountains operates.

The supply channel (s) deposits water into the feeding-tank (t), from which water flows through the delivery-pipes (m, n). Pipe (m) deposits water into the lower-head of the fountain to produce the shape of a shield. At the same time, pipe (n) brings up the water to the upper-head, from which three arcs of water surge out. To keep the perpetuity of the fountain, the same amount of water falling into the basin is to be discharged. Through the flow-way (f) the water is lead into the nearby river or stream from which the supply was initially taken. See figure (112).



وفي وسطها قصبة اخرى محكمة اللحام حتى يبرز منها نوفرة في وسط البركة
ويكون القصبة الصغيرة بارزة من الكبيرة [illegible] صفيحة مستديرة مقعرة
وتخرق ثقبا في وسطها بقدر القصبة الكبيرة ونضعها فيها مقلوبة وتلحمها
ثم تعمل صفيحة اخرى مثلها وتقعرها كتقعيرها سوا وتخرق في وسطها
بقدر القصبة الصغرى وتضعها فيها مقلوبة ايضا مطبوقة على اختها
بحيث يكون بينهما تخلل يسير قدر ثخن نصف كراس ورق ثم تركب على
القصبة الصغرى ثلاثة انابيب او اربعة او خمسة بمقدار ما تختار
ليخرج ماؤها صولجانا فمن التوابع المقرر انه اذا اطلق الماء من الحوض
نزل في كلا القصبتين وخرج من الكبيرة وانحصر من الصفيحتين وخرج من
بينهما صفة خيمة وبرز من الانابيب صولجانات بعدتها

Fig. (111) The drawing of the fountain by Taqi al-Din that is shown in al-Hassan's book.

This fountain-head is designed to produce a shield shape and in the same time three arcs.

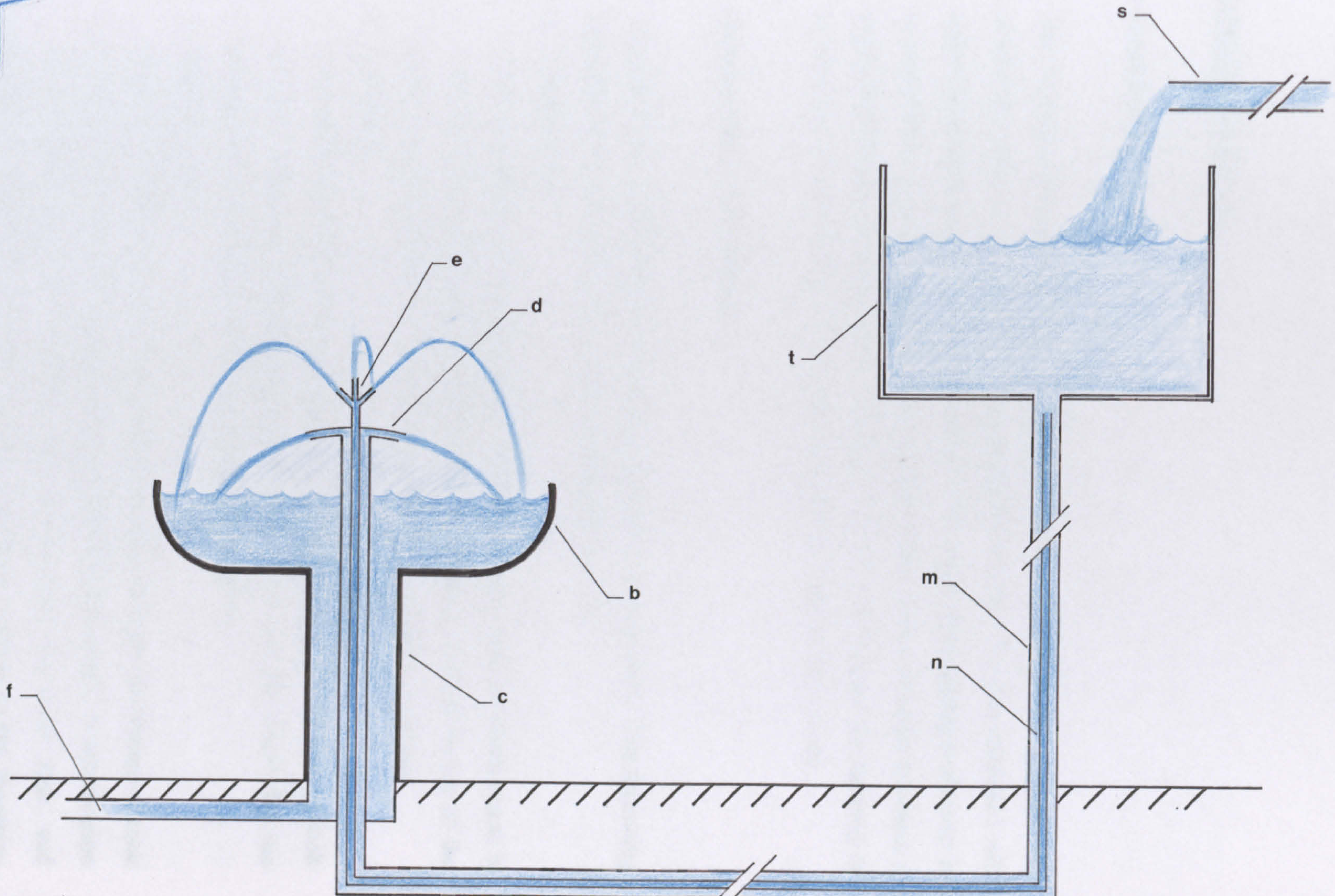


Figure 112: . Reconstruction of the fountain with detailed diagram of its head.

5. FOUNTAIN NO. (2)

5.1. About the fountain

This fountain alternates between producing water in the shape of a shield and producing water in a vertical jet, for equal period of time. For this fountain I will apply the mechanism of the Tipping-bucket. The high static pressure of water is an essential to this particular fountain, as well as the others, in order to obtain a proper flow to the fountain-head. Figures (113) and (114) show the drawing of the mechanism and the fountain as they appeared in Taqi al-Din's work.

5.2. Construction of the fountain

The machinery of the fountain consists of five main components. The following description is to be read in conjunction with Figure (115).

a. Feeding tanks:

   Some distance away from the pool, a high housing is built in which a tank is constructed and divided into two (a, b). An axle (f) is fixed on top of the partition between the two tanks with two bearings (e) fitted to its end.

b. Sub-tanks

   Two small tanks are placed in the centre of the far end of each feeding-tank (t_1, t_2). A siphon is fitted into each tank to drain out the water that has already been discharged from the tipping-bucket above.

c. Delivery pipes:

   As with fountain No. (1) a wide pipe (m) descends from the bottom of tank (a) along the way down and terminates at the fountain-head. A narrow pipe (n) descends from the adjacent tank (b) to meet the other pipe, and penetrates through it so that the pipes terminate together at the fountain-head.

d. Balanced-delivery pipe:

   In the centre of this pipe is funnel (g), into which the supply channel (s) discharges the water. A bleeding-pipe (h1, h2) tips the water in turn into tipping-buckets. The pipe is set in an imbalanced position so that it tilts towards one of the two tanks.

e. Tipping-buckets:

   Tipping-buckets (k1, k2) are set underneath the two bleeding-pipes, facing the tank wall. An inclined projection (q) meets the balanced-pipe as it is being tilted to its side.

5.3. Construction of the fountain-head.

Both pipes (m, n) are brought up in the centre of the basin, but pipe (n) is raised a bit higher than pipe (m). A concave disc is soldered to the rim of pipe (m) facing downwards, and a similar disc is positioned on pipe (n) and brought close to the other disc, leaving a small gap, then is soldered in position. Water passing through pipe (m) flows between the two discs to create the shape of a shield. When water passes through pipe (n) it produces a vertical jet.

5.4. How fountain operates.

Water runs from supply-channel (s) into funnel (g), then through balanced-delivery pipe (d) into tank (b). Most of the water is discharged into the tank from pipe (c1) on the balanced-pipe. Meanwhile some of the water tips into the tipping-bucket (k2) through the bleeding-pipe (h2). Water descends from the tank running through the narrow pipe (n) up to the fountain-head to produce a vertical jet. As the tipping-bucket (k2) is filled for an hour or so it tilts down discharging the water into the sub-tank (t2), where, at the same time, the metal projection on its rear-end lifts up the balanced-pipe, causing it to tilt towards the adjacent tank (a). Then the counter-weight (w) forces the bucket to tilt back to its horizontal position and its contents are poured out. The water discharged into the sub-tank must be raised above the level of the siphon, so it drains out the water from the tank. The operation is repeated in the adjacent tank (a), but the water this time runs through the wide pipe (m) terminating at the fountain-head (o) to produce the shape of shield for the same period of time as the previous emission. The fountain changes its shape continuously by this repeated mechanical motion as water flows into the machine constantly.

Fig. (113). Taqi al-Din's drawing shows the tipping-bucket mechanism, in this rather crude and presumably uncompleted drawing.

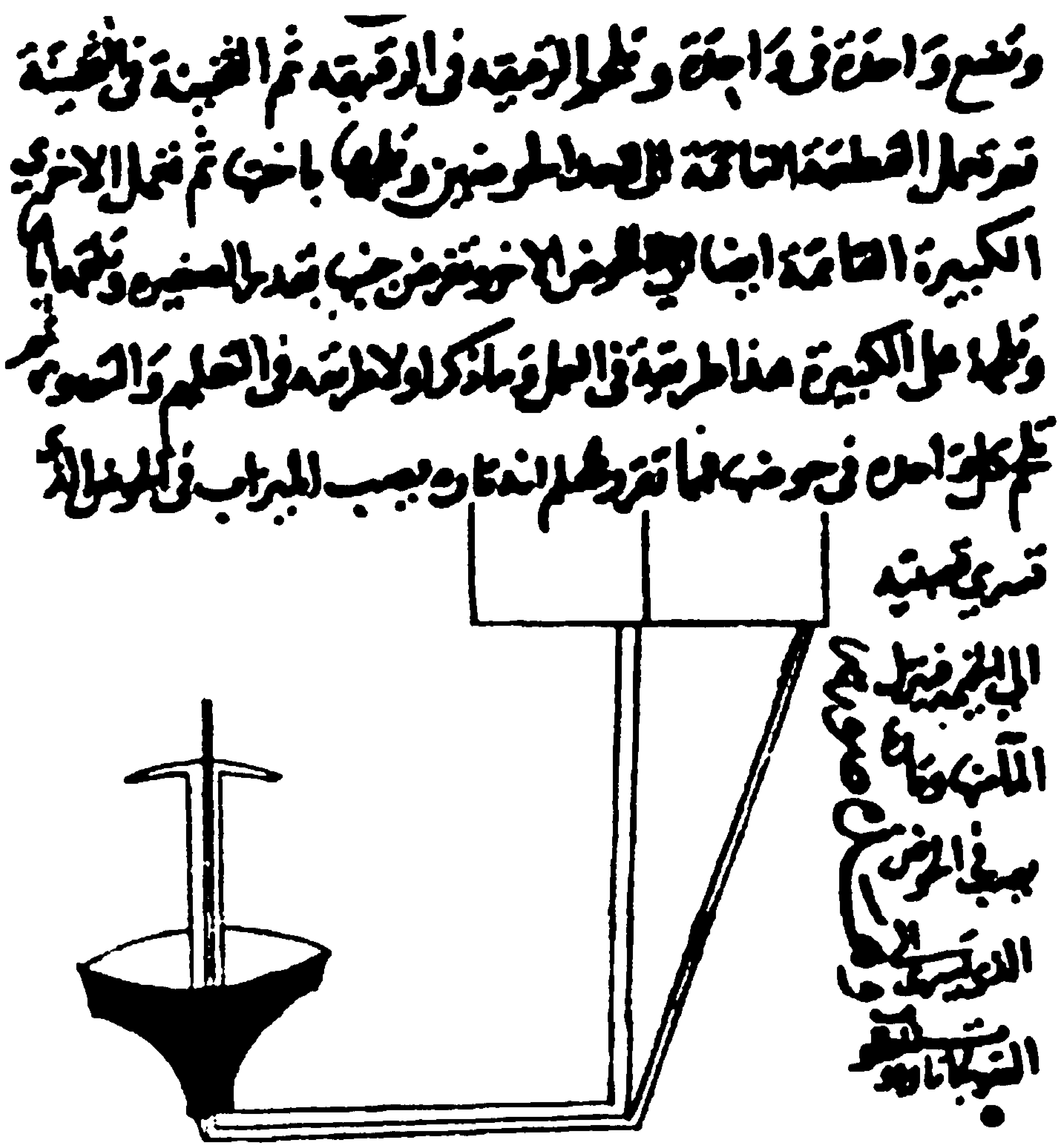


Fig. (114). In this drawing Taqi al-Din shows the fountain construction without the mechanical operating device as is the case with other models.

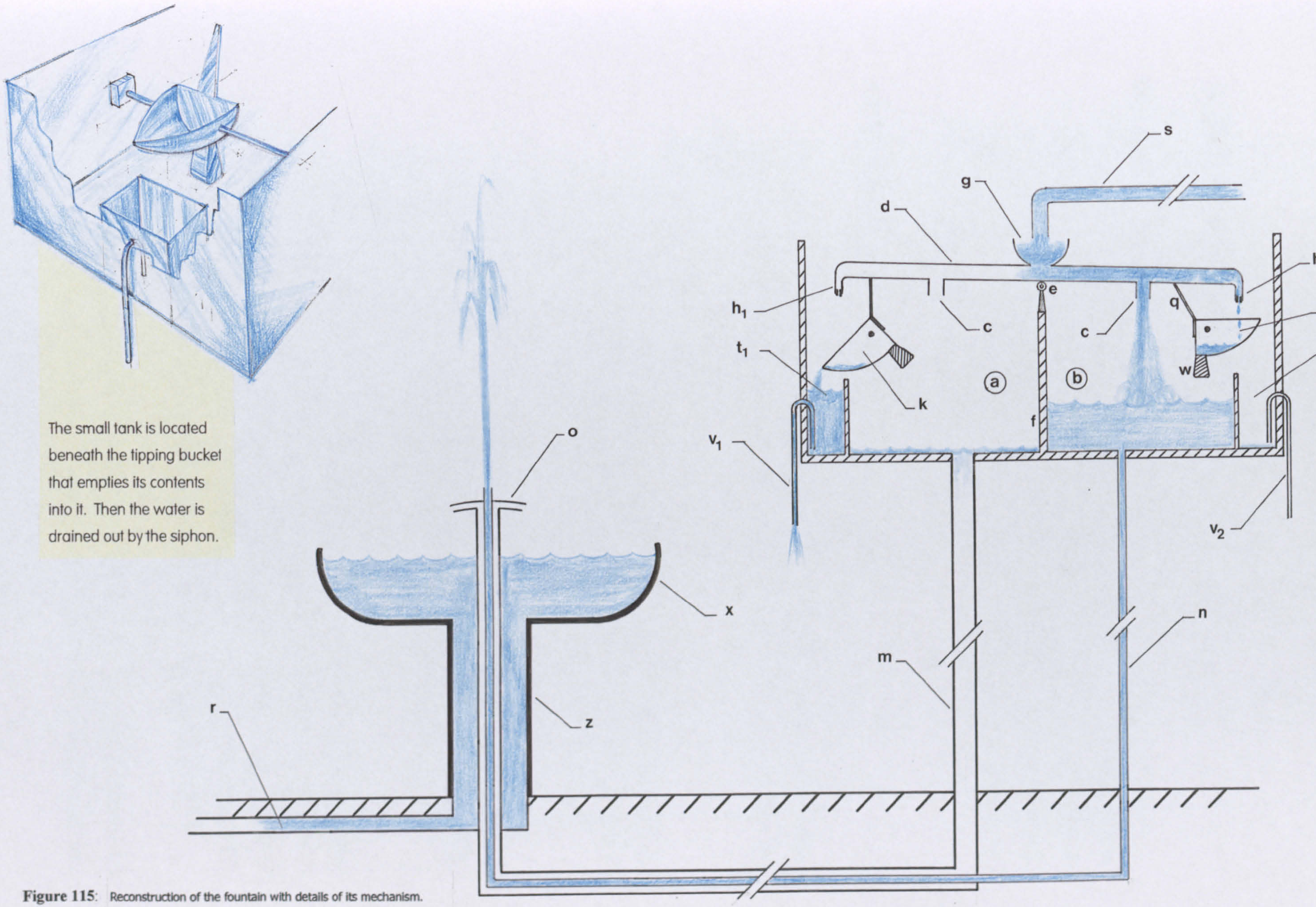


Figure 115: Reconstruction of the fountain with details of its mechanism.

6. FOUNTAIN NO. (3)

6.1. About the fountain:

The mechanical concept in this fountain is based on the tilting-buckets mechanism. The machine operates two fountains producing the shape of a shield or the shape of a tree alternately. Taqi al-Din provided a clearer drawing in figures (116, 117), accompanied with a clear description on the machine and fountain construction.

6.2. Construction of the device

The machine of this fountain comprises five main components. For a much clearer understanding, the following description is to be read in conjunction with figure (118).

a. Feeding tanks:

   Some distance away from the pool, a high housing is built in which a tank is constructed and divided into two tanks (a, b). An axle (f) is fixed on top of the partition between the two tanks with two bearings (e) fitted to its end.

b. Sub-tanks

   Two small tanks (t_1, t_2) are placed at the centre of the far end of each feeding-tank (a, b). A siphon (v_1, v_2) is fitted into each tank to drain out the water that has already been discharged from the tilting-bucket above.

c. Delivery pipes:

   A wide pipe (m_1) is fitted to the bottom of tank (a) and brought up to the fountain-head (1). Likewise pipe (m_2) is linked to tank (b) and terminates at the head of the fountain (2). A narrow pipe (n_1) is attached to the bottom of tank (a) joining pipe (m_2) and then ascending to the head of fountain (2). The same arrangement is made with pipe (n_2) that descends from tank (b).

d. Balanced-delivery pipe:

   In the centre of this pipe is funnel (g) into which the supply channel (s) discharges the water. Two bleeding-pipes (h_1, h_2) are branched from each side of the balanced-pipe, close to the centre, and stretch to tip the water into the tilting-bucket in the opposite tanks.

e. Tilting-buckets:

Tilting-buckets (k1, k2) are set underneath the two bleeding-pipes (h1, h2). A measured amount of water causes the tilting-bucket to tilt and discharg its contents into the sub-tank underneath.

6.3. How the fountain operates:

Water flows from the supply channel (s) into the funnel (g) on the balanced-pipe (d). Pipe (c2) deposits the water into tank (b) and at the same time the bleeding-pipe (h2) tips water into the tilting-bucket (k1). From tank (b) water descends through pipes (m2, n2). Pipe (m2) delivers the water up to the head of the fountain (2) to produce the shield shape. Fountain (1), on the other hand, is emitting the shape of a tree as pipe (n2) deposits the water into a multi-holes sphere. Once the tilting-bucket is filled with the measured amount of water, it ought to tilt down and discharge its content into the sub-tank underneath. This, of course, causes the balanced-pipe to tilt up from the opposite side and diverts the flow of water to the adjacent tank (a). The water being poured into the sub-tank (t2) is instantly to be siphoned as the water rises above the level of the siphon (v2). Here the alternation occurs, as fountain (1) produces the shield shape instead of the tree, whereas fountain (2) changes to a shield-shape emission for the same time of the previous session. Both fountains maintain the perpetual flow as water continues to be deposited into the feeding-tanks.

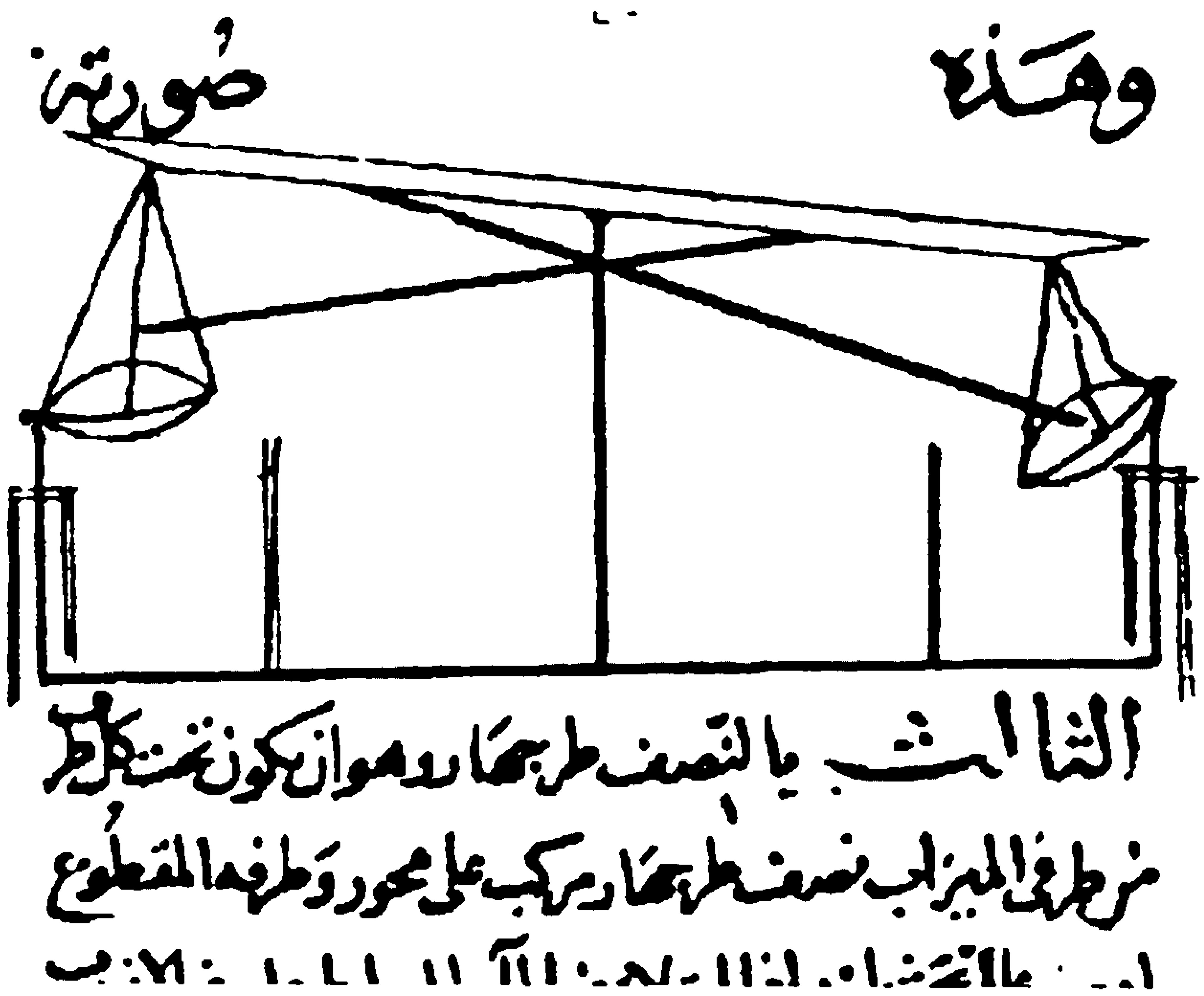


Fig. (116) Taqi al-Din's drawing of the tilting-bucket concept as it shown in al-Hassan's book.

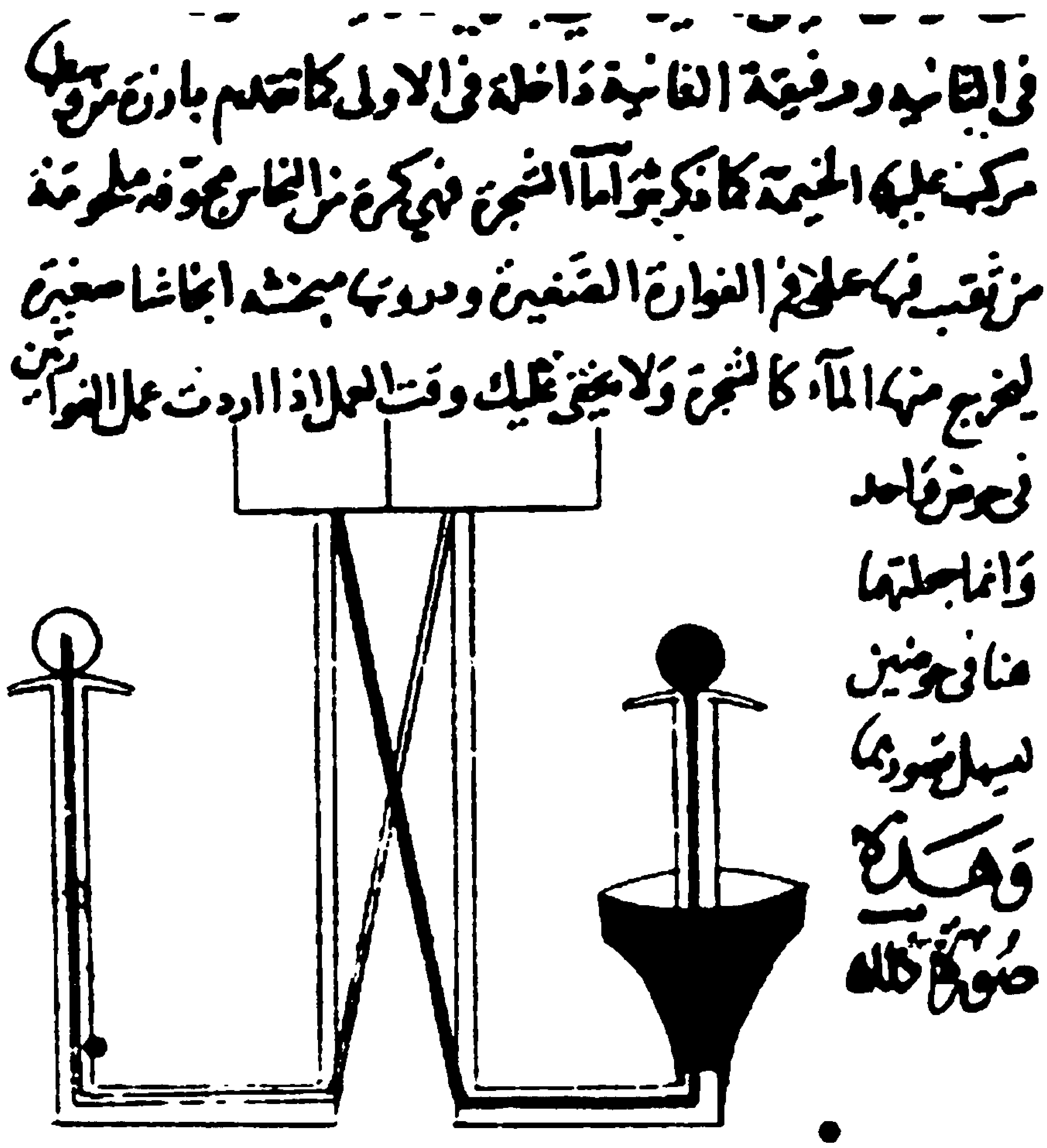
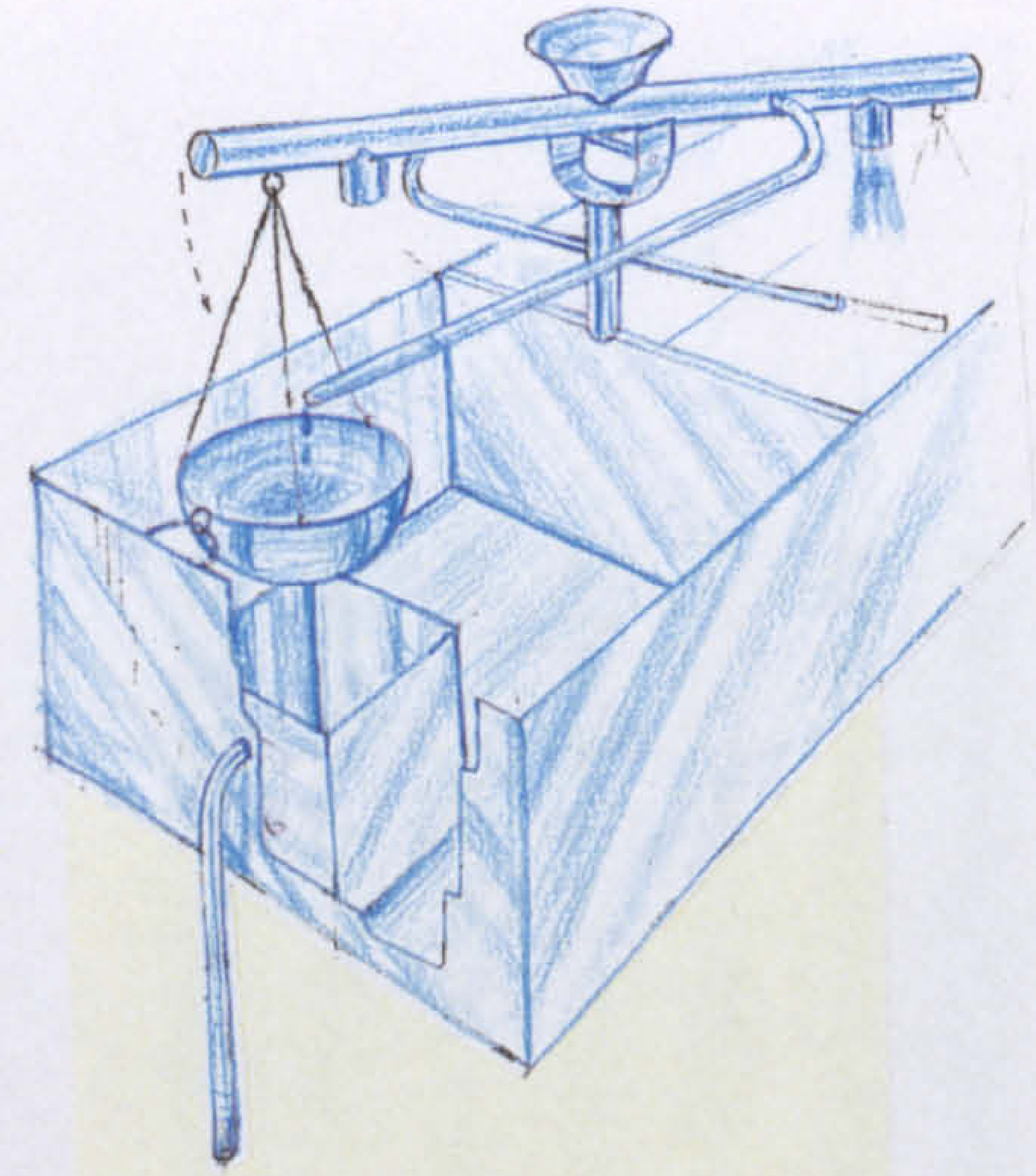


Fig. (117). The construction of the fountain by Taqi al-Din as shown in al-Hassan's book.



This drawing shows the small tank that is set to receive the water from the tipping-bucket. The water then is evacuated from this tank by the siphon mechanism.

The sphere on the fountain-head is to produce numerous fine jets creating a tree shape.

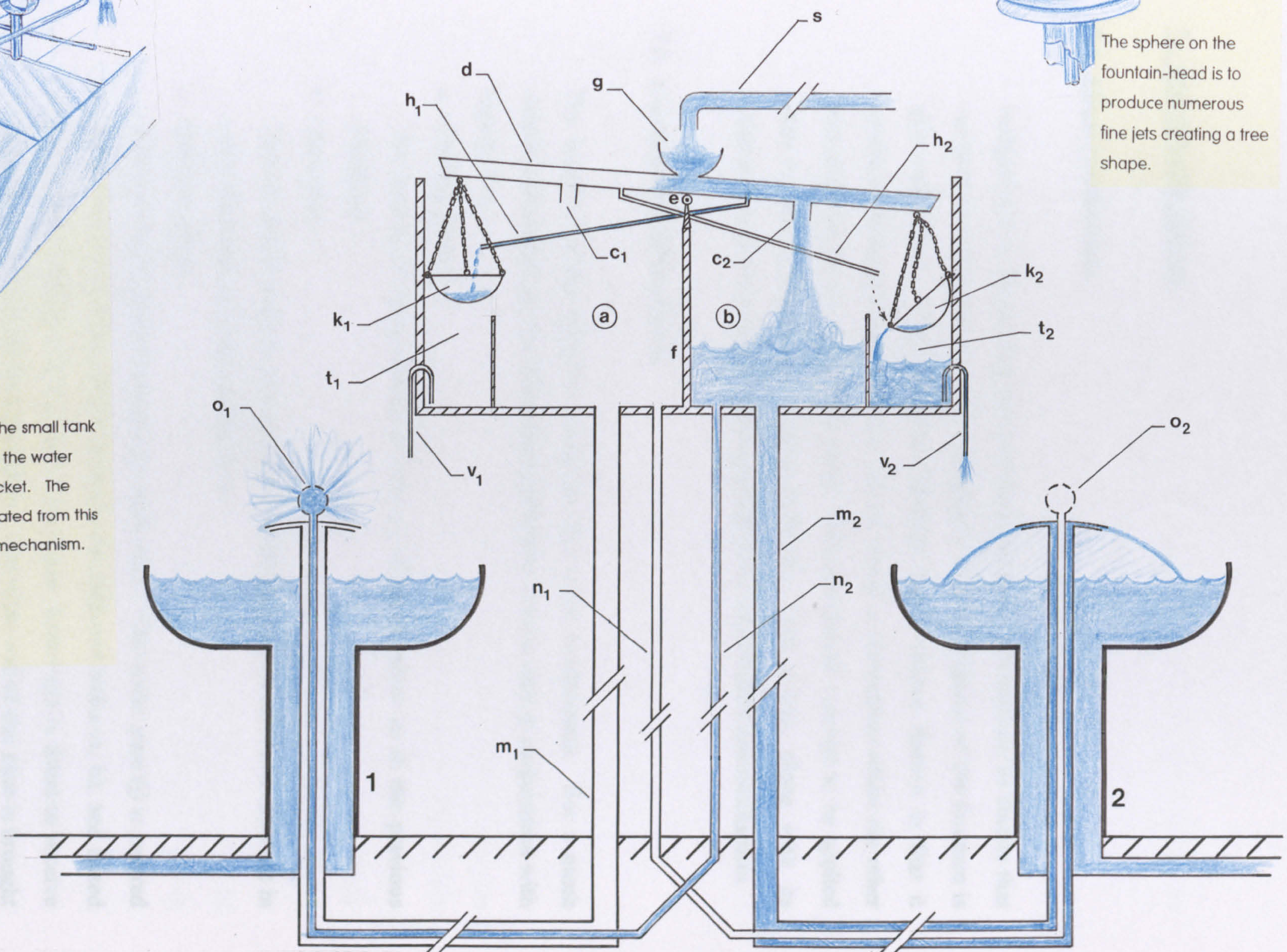


Figure 118:

This reconstruction of the fountain shows in detail the delicate mechanism used by Taqi al-Din.

7. FOUNTAIN NO. (4)

7.1. About the fountain

In figure (119) Taqi al-Din showed the structure of the fountain so clearly that we have no difficulties in understanding it. The description of the fountain is also very clear. This particular fountain has a unique feature in that it produces three types of emission, one of which is permanent whilst the other two alternate for an equal time scale. The mechanical concept to be applied here is the lifting-float. Figure (120) by Taqi al-Din, along with its description, give us a good understanding of its construction and mechanism.

7.2. Construction of the device

The machine of this fountain comprises five main components. For a much clearer understanding, the following description is to be read in conjunction with Figure (121).

a. Feeding tanks:

   The setting of these adjoining tanks (a, b) is the same as in the previous fountains.

b. Sub-tanks

   The two small tanks (t_1, t_2) with their siphoning system remain as they are in other fountains without modification.

c. Delivery pipes:

   There are three pipes inserted into each other. The wider pipe (j) is centred where the partitioning wall is between the adjacent tanks (a, b), and raised above their bottom. To the rim of this pipe, funnel (y) is fitted to receive directly water from the balanced-pipe. The other end of this pipe is brought up in the middle of the basin and attached to the lower-head (z) of the fountain. From tank (a), pipe (m) descends to where it meets pipe (j) and penetrates through it ending up at the middle-head (x) of the fountain.

Likewise pipe (n) is linked to tank (b) and then inserted into pipe (m) to terminate at the upper-head of the fountain.

d. Balanced-pipe:

   Three pipes are branched on either side of the balanced-pipe. On the far end of each side two bleeding-pipes (h1, h2) are fitted, both of which tip water into the sub-tank underneath. Close to the middle of either sides the short pipes (c1) and (c2) are branched to deposit the water into tank (a, b). Two other long pipes (p1, p2) are set close to the centre of the balanced-pipe from which water flows directly into the funnel (y).

e. Lifting-float:

   Both lifting-floats (k1, k2) are positioned inside the sub-tanks to serve the alternation mechanism.

7.3. How the fountain operates.

Water flows into the balanced-pipe through the funnel (g) that receives the water from the supply channel (s). On the far end of the balanced-pipe, the bleeding-pipe (h2) tips water into the sub-tank (t2) underneath. Meanwhile pipe (c1) discharges water into tank (b), whereas pipe (p2) deposits water into the delivery-pipe (j) through its funnel (y). Pipe (j) delivers the water being deposited into it up to the lower-head of the fountain to produce the shield shape, which is to be the permanent emission. From tank (b) the delivery pipe (n) carries the water and terminates at the upper-head to produce three arcs of water in different directions. This session will last until the collected water in the sub-tank (t2) comes to the level allowing the lifting-float (k2) to push up the balanced-pipe, causing it to tilt towards the adjacent tank (a). The siphoning system must act immediately as the water covers the siphon (v2). As the alternation occurs the operation is repeated in tank (a). The emission of the shield continues as pipe (p1) deposits the water into pipe (j), whereas pipe (m) delivers the water being discharged into tank (a), up to the middle-head of the fountain and deposits it into the multi-holes sphere to produce a tree-like emission. Therefore, the interval occurs between the three-arcs and the tree-like emissions for the same amount of time, whilst the lower-head produces the shield shape permanently.

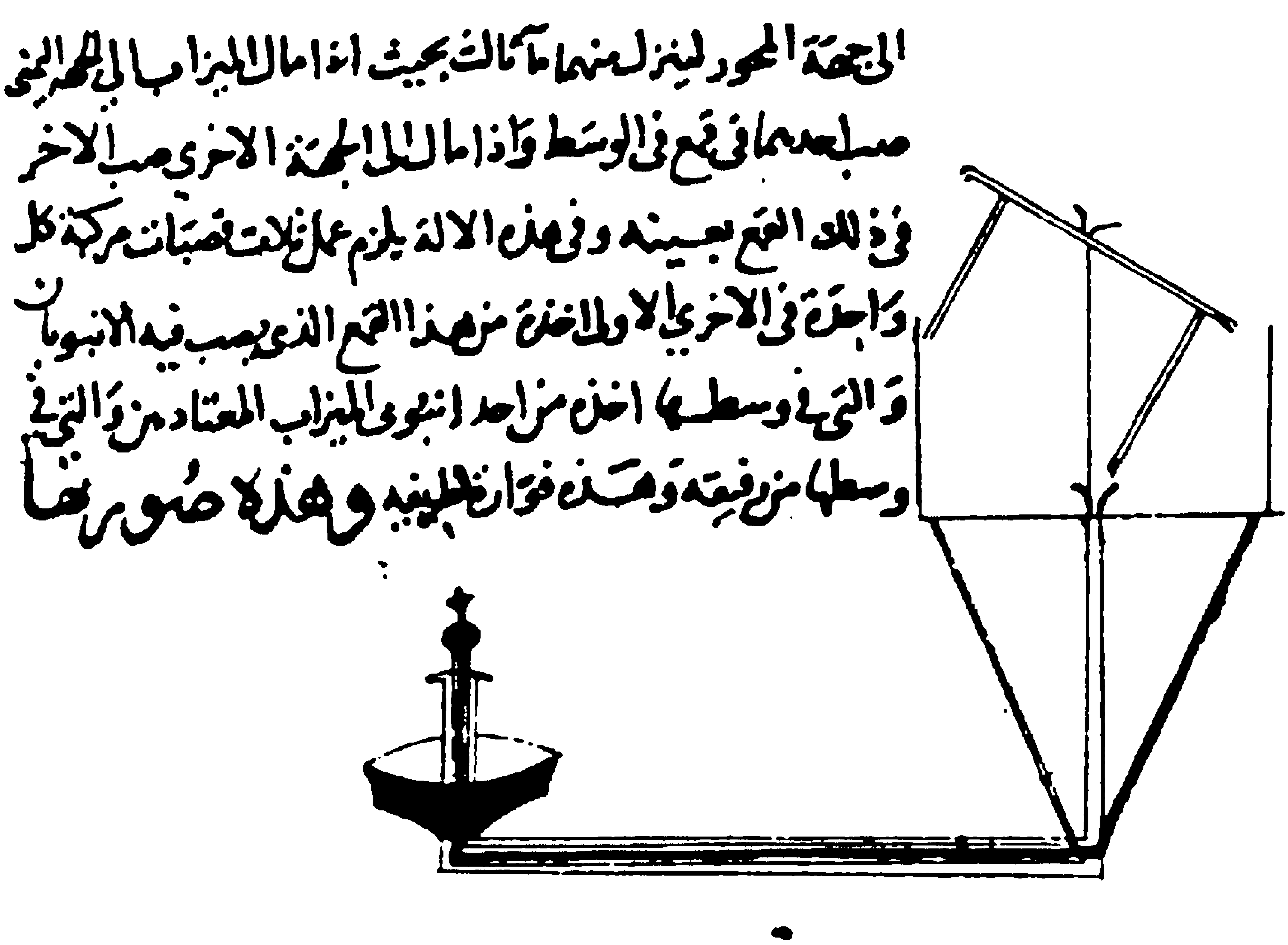


Figure (119) The construction of the fountain by Taqi al-Din as shown in al-Hassan's book.


عصًا واقصه فيه لترفع للميزاب اذا ارتفعت العوّامة ومقلب بازن
طرفه الطويل الى الخارج من خرق في اعلى الحوض بحيث لا يمتلي الحوض
حتى ينغمر المقلب بالماء فاما الى الميزاب وضبط الماء من انبوبة الكبير
على الجهة التي يميل عليها الزمر وعبر ينزل من الانبوب الصغير الى هذا
الحوض ما يملاه في الزمان الذي قدرناه وما امتلائه ارتفعت العوامة
ورفعت طرف الانبوب فانقلب الى الجهة الاخرى التي انقلبت اليها
وينزل الماء من الانبوب المقابل لهذا ايضا حتى يملا الحوض وترتفع العوامة
فتقلبه الى الجهة الاخرى وهذه صورته

Figure (120) The drawing of the lifting-float mechanism by Taqi al-Din as shown in Al-Hassan's book.

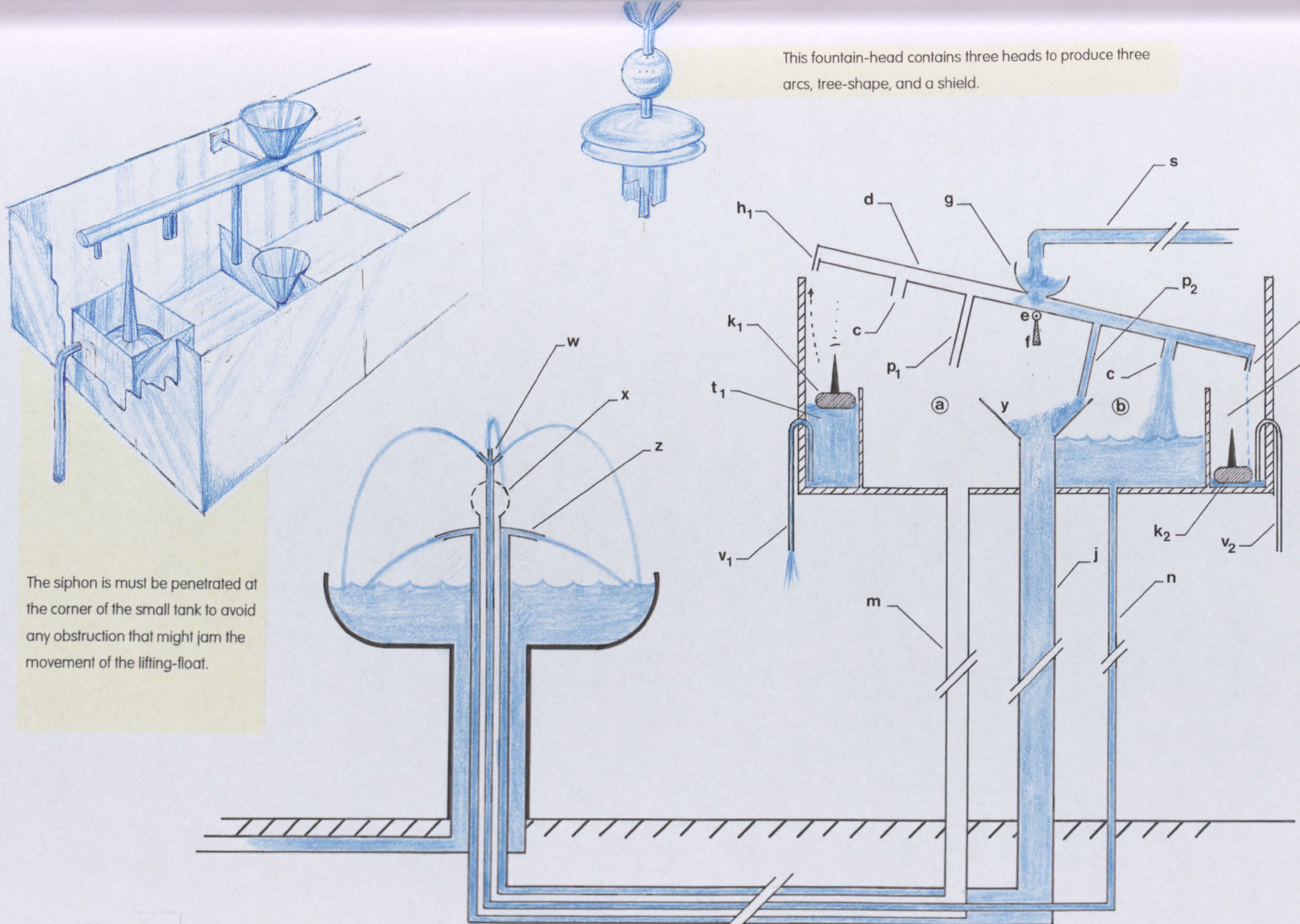


Figure 121:

Reconstruction of the fountain drawing in which its mechanism is clear and easy to be understood.

A comparison of the Works of Banu Musa, al-Jazari and Taqi al-Din

In this comparison I will bring into focus the main characteristics of the engineering and design of the fountain in the work of the three engineers. Taking the work of the first engineers, Banu Musa, who were the most influential figures in the history of Islamic engineering and technology, it is safe to say that their design of fountains was in a technical term revolutionary. This was not just confined to the engineering aspect of their work; in fact they showed such genuine development in the concept of designing and the philosophy of the fountain that it manifested itself throughout the whole perspective of Islamic culture.

Banu Musa were not only well advanced from their predecessors, Heron of Alexandria and Philon of Byzantium, but were also were quite distinctive from their successors, Taqi al-Din and al-Jazari. We find no similarities in the work of Banu Musa and the work of their predecessors, in particular the Greco-Hellenistic engineers. The only three fountains (figures 122, 123 and 124)[1] which were designed by Heron of Alexandria show an example of fountain design which mainly based on pneumatics principle, although they are not necessarily practical. Banu Musa, on the other hand, did not base their designs on such pneumatic principles, they were rather practical and clear in their design. They introduced a number of unique concepts of designing the fountain, which were based on ingenious mechanical ideas. Banu Musa, however, never based their designs on theoretical ideas that sometime far from being practical; they developed their designs through making and testing either by themselves or under their supervision. This is why their work is characterised by its innovativeness and supreme practicality. Hill writes " compared to the Greek works, they contain far less theory and a much greater degree of engineering inventiveness"[2]. The popularity of the fountain in Islamic culture can be attributed firstly to the practical design of the fountain introduced by the engineers which can be built in its highly sophisticated version or the simple one where there was a running water

[1] See *The Pneumatic of Hero of Alexandria*. Introduced by Marie Boas Hall. Model 54, 47 and 15.
[2] Banu Musa. *The Book of Ingenious Devices*. edited by Donald Hill (1979) p. 19

source. In contrast, fountain design in the work of Heron was limited to the use of wind, or heat derived from the sun to activate the pneumatic mechanism, so in effect the utility of the fountain is more restricted to a particular time, place and even to a specific size. Secondly, as mythology and egoism were the prime motivation of design inspiration for Heron and Philon, contrarily, the design of Banu Musa, and Muslim engineers in general, was integrated within the fabric of the Islamic culture where piety and simplicity formed a unitary coexistence between science and art. Through this plastic form of coexistence the artistic, spiritual, and aesthetic qualities were manifested. Although the engineering triumph of Banu Musa's work appears in the complexity of the mechanical concepts applied to operate the fountain, in contrast the design of the fountain bears that simplicity which is the dominant characteristic of all Islamic arts. We may gather that the fountain in Banu Musa's work was revolutionised the attitude of designing fountain through which the fountain served its function more efficiently and delivered its cultural symbol, as both were imbued with genius.

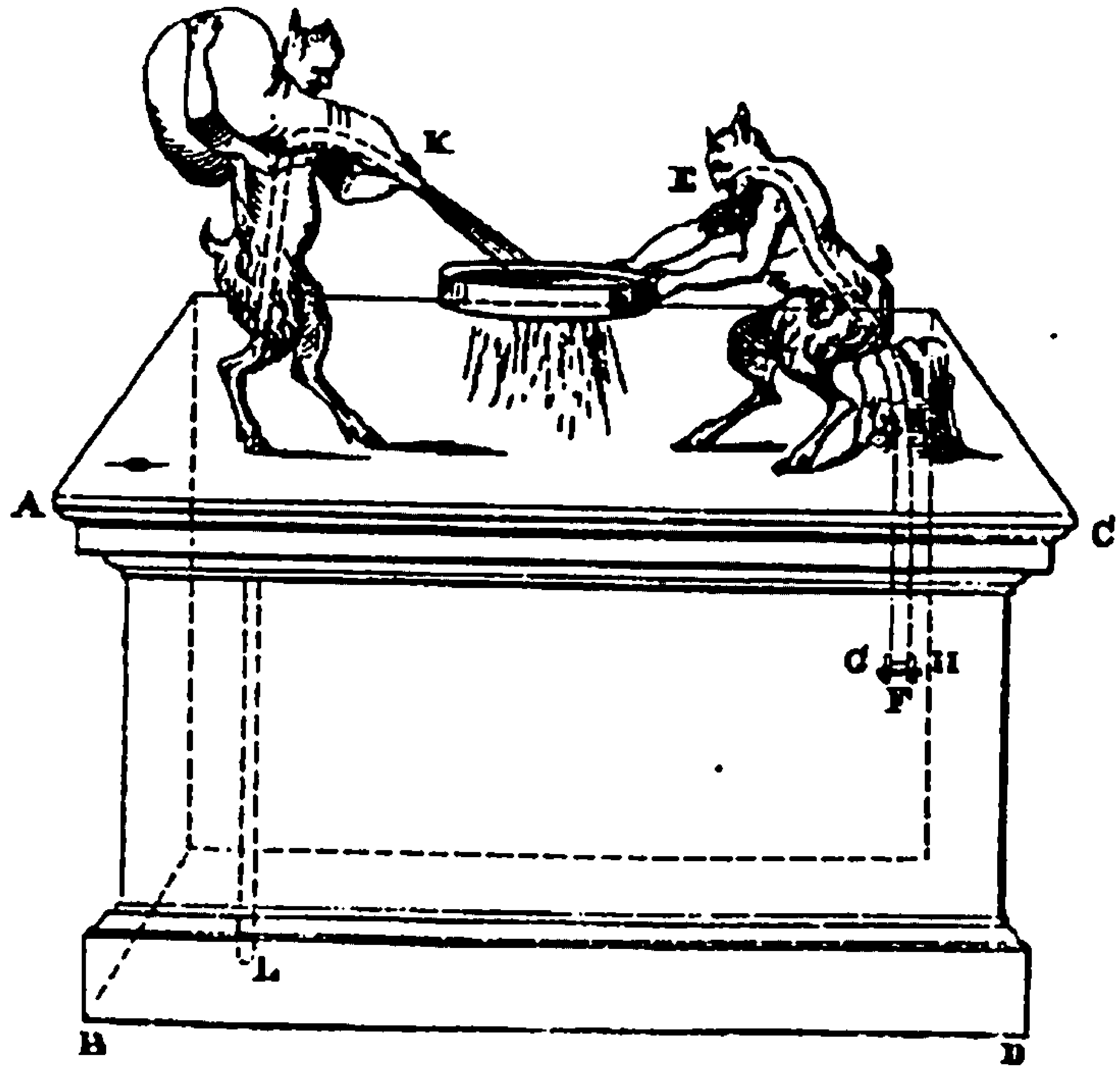


Figure (122)

The water in this fountain is driven from the mouth of a Wine-skin in the hands of a Satyr, by means of compressed air.

As wind is blown through the mouth of the Satyr on the right; air will be compressed inside the pedestal, in which there is an amount of water. The valves on the wind inlet pipe EF and on the water outlet pipe LK control the water spouted out through the wine-skin.

This fountain is by no means is practical regarding the size and the scale of the pedestal and the Satyrs as shown in the drawing. The air inlet is far too small to catch a sufficient wind and drive it into the pedestal to produce the adequate pressure that would force the water out through the wine-skin.

Figure (123)

This fountain is designed to trickle by the action of the sun's rays.
The heat generated inside the globe by the sun's rays is to drive the water through the siphon passing the funnel into the chamber. The water will be sucked up into the globe as the shade casts on it.

Although the principle of this fountain is practical, it is restricted to a certain time of the day when the temperature is enough to heat up the sphere. Therefore, it is, in my judgement, impractical and is a pneumatic device rather than a fountain.

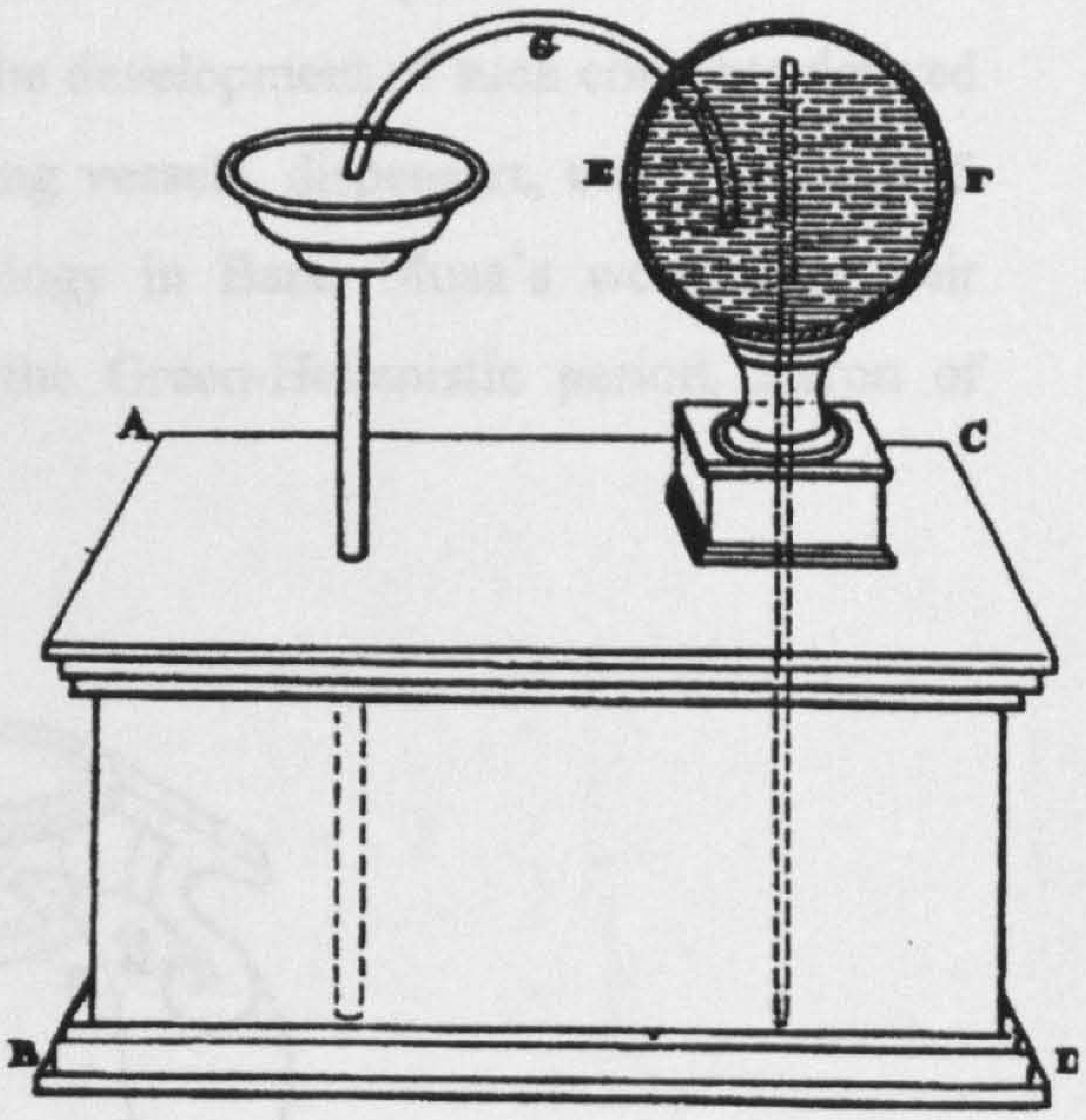
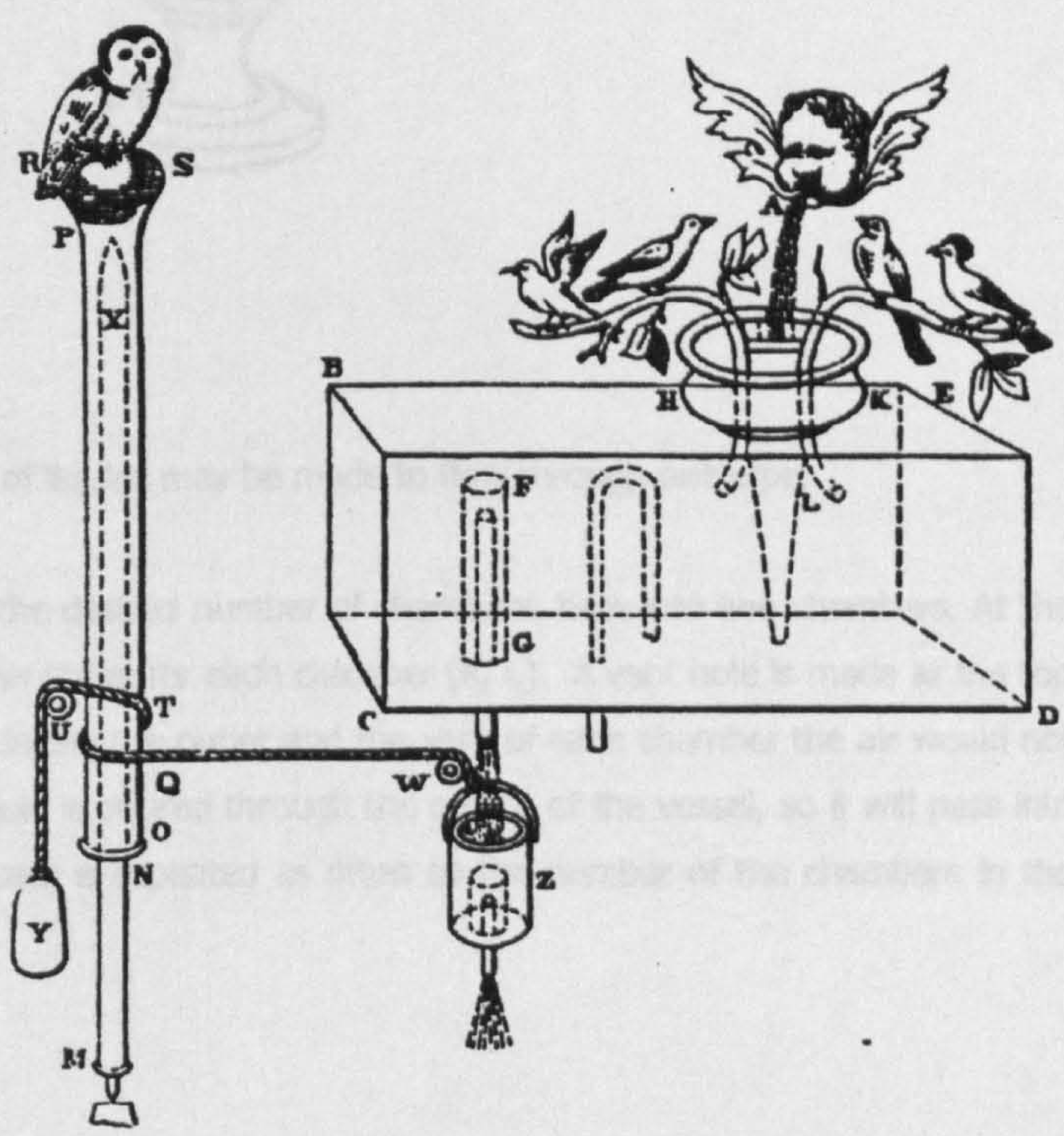


Figure (124)

Birds made to sing, and be silent alternately by flowing water. Water in this fountain is used as an operating power, by the flow of which the pneumatic mechanism is activated that is mainly based on siphoning. Although this device is conspicuously practical, it again can not be considered as a real fountain. It is in fact very much a kind of novelty work that was common in Greek culture.



Despite the fact that they had been influenced by the work of Heron, they seemed not to have been convinced that to develop the pneumatics concepts of Heron's fountains was the way forward. Yet, they worked on the development of such concepts derived from the sophisticated design of trick drinking vessels, dispensers, etc. Figures 125 and 126 demonstrate the advanced technology in Banu Musa's work than their predecessor the distinguished engineer of the Greco-Hellenistic period, Heron of Alexandria.

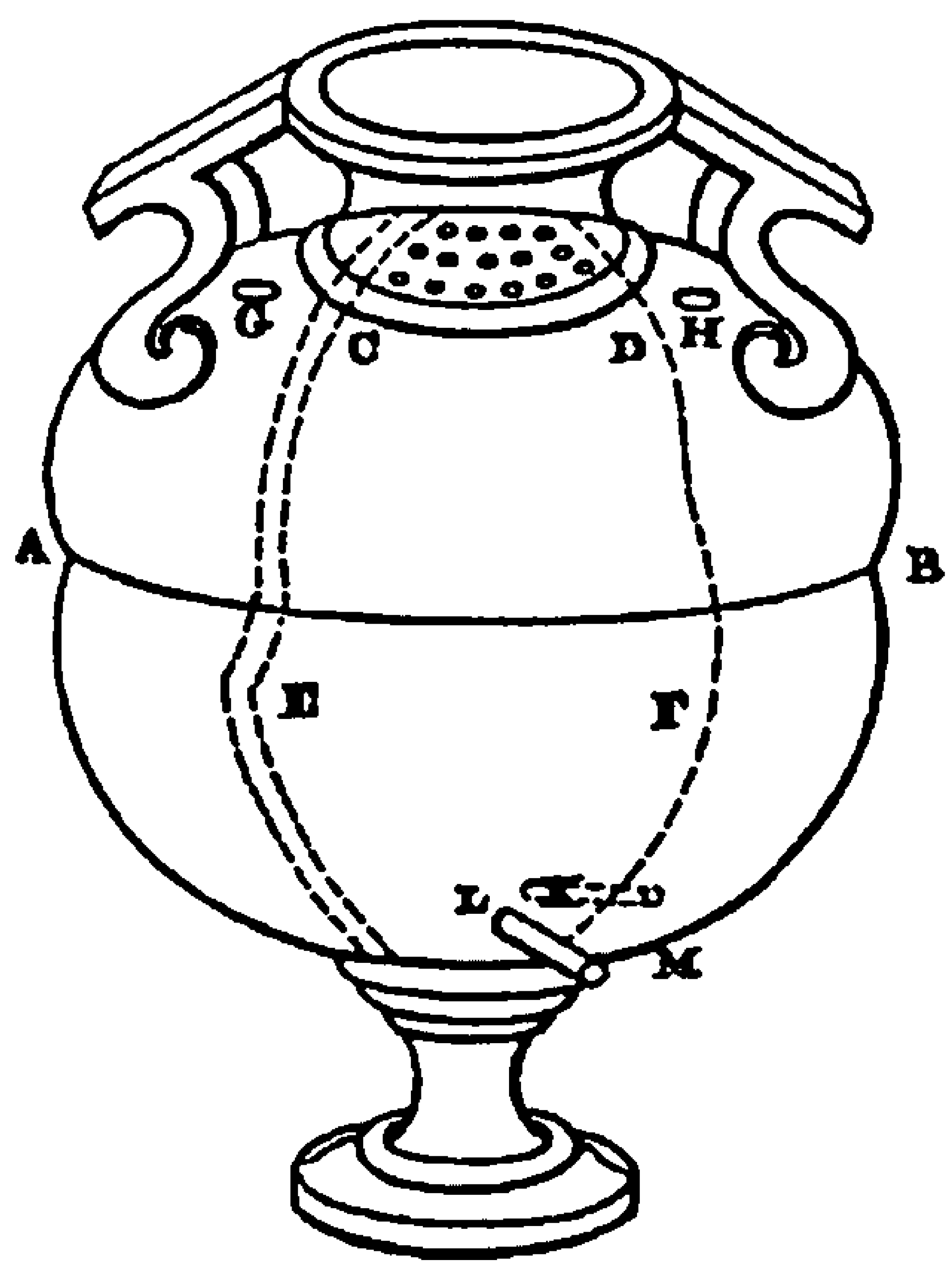


Figure (125) Heron's model 22[3].

A vessel from which a variety of liquids may be made to flow through one pipe.

The vessel is partitioned into the desired number of chambers, here into two chambers. At the bottom of the vessel there is an outlet for each chamber (K, L). A vent hole is made at the top of each chamber (G, H). By closing the outlet and the vent of each chamber the air would not find its way out as the first liquid is poured through the mouth of the vessel, so it will pass into the other chamber. The process is repeated as often as the number of the chambers in the vessel.

[3] See *The Pneumatic of Hero of Alexandria*. Introduced by Marie Boas Hall.

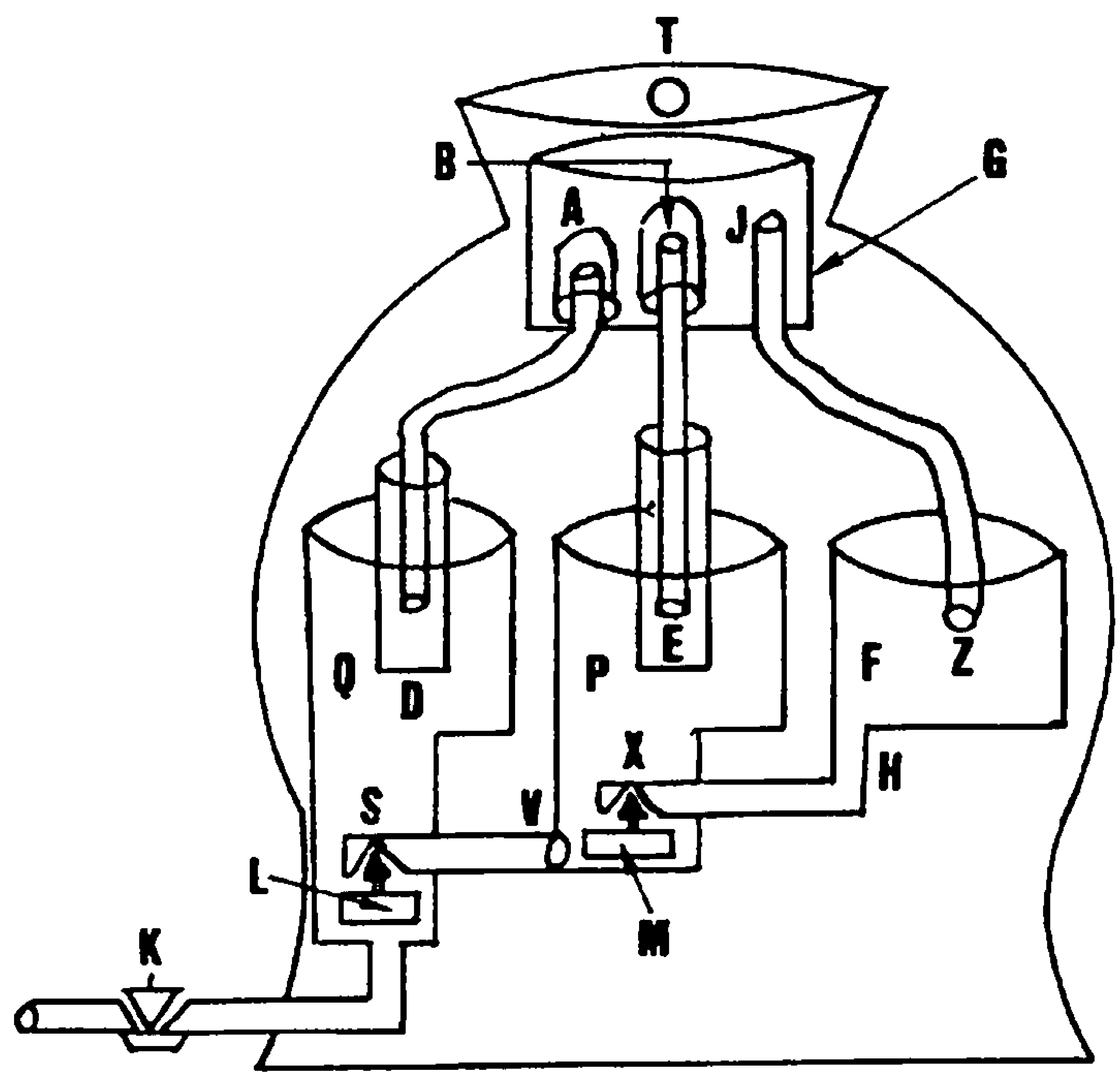


Figure (126) Banu Musa's trick vessel. Model 43[4]

Banu Musa's trick vessel, which is similar to that of Heron, but far more sophisticated. Three different liquids are extracted from this vessel in succession.

The mechanism here is based on the double-siphoning and conical-valve. To describe in short how it works; as the first liquid is poured through the mouth of the vessel, it runs through the double-concentric siphon AD and into tank Q. Because of the level setting of the receiving pipes AD, BE, and JZ the process is repeated when pouring in the other two liquids. Once the tap K is opened the liquids are extracted in succession, so as the first tank Q is being emptied out the float L descends, allowing the second liquid to pass through the joining pipe and out of the tap K. This mechanism is repeated in the second tank P.

[4] See Banu Musa. *The Book of Ingenious Devices*. edited by Donald Hill,

Just as the work of Banu Musa differed greatly from that of their Greek predecessors, so too the work of their successors al-Jazari and Taqi al-Din differed from them. However, to compare the work of Banu Musa to their first prominent successor al-Jazari, we in fact come to experience a new engineering concept with an extraordinary wealth of design details. Al-Jazari in his design of the fountain tended to use the concepts and techniques that were common in water-clocks at the time, for example the tipping-bucket and the lifting-float (see figures 93, 101). It is not surprising if we come to know that al-Jazari designed and made a numbers of water-clocks that were designs of great complexity and perfection; are to be regarded as the climax of achievement in that period.

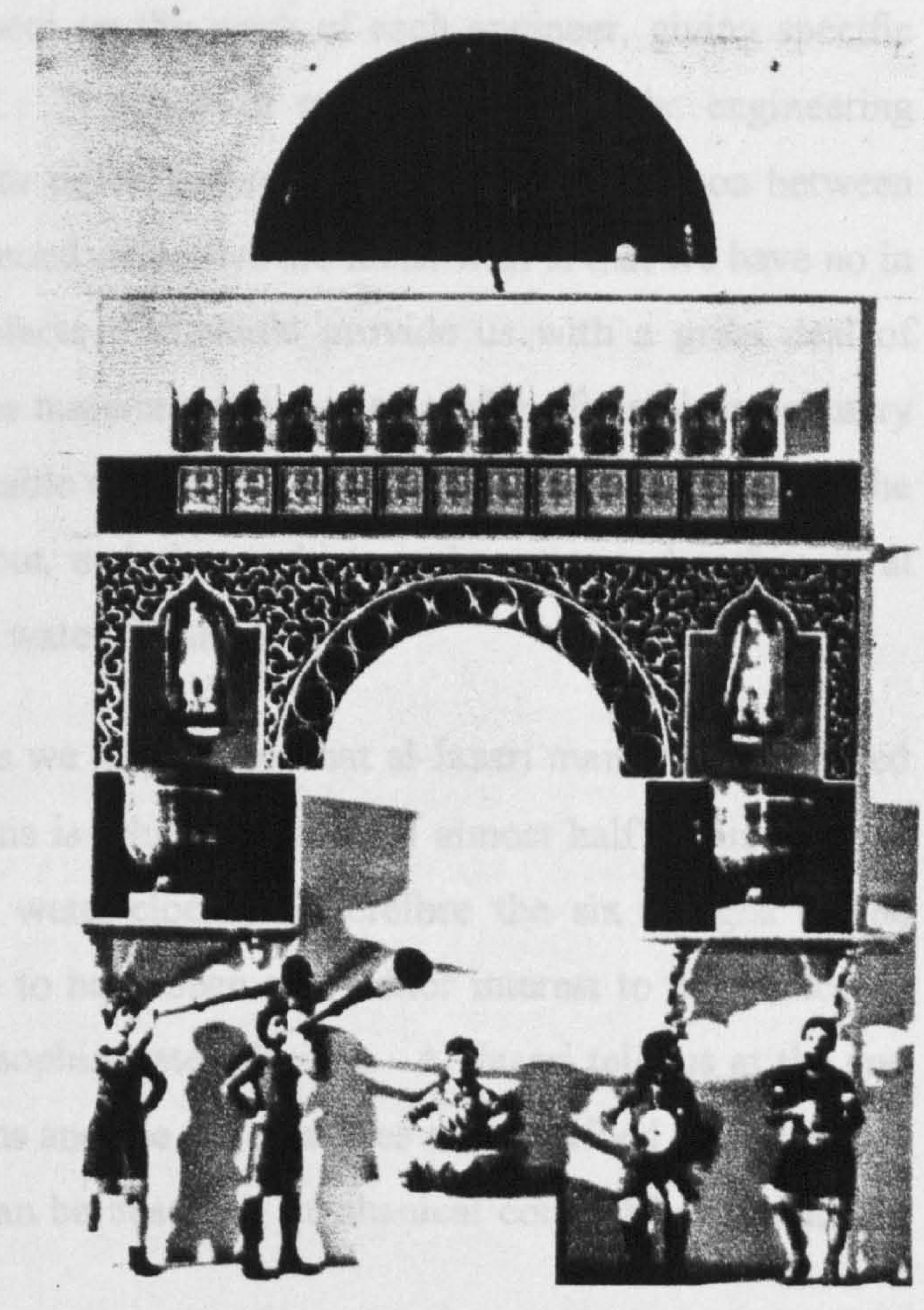
In modern times, some of al-Jazari's devices were reconstructed, executed under the supervision of Donald Hill. It must be said that the realisation of his contribution to the exhibition ' Science and Technology in Islam' in the context of the World of Islam Festival in London is of major importance. David King writes that this exhibition provided

> "An opportunity to test the firmly held and strongly iterated opinion that all al-Jazari's machines were totally impractical. For the exhibition held in the Science Museum in 1976, three of al-Jazari's machines-a phlebotomy device, a double-acting pump and the 'castle' water-clock- were reconstructed. All three were built without great difficulties following al-Jazari's instructions and all three worked well. Particularly impressive was the mechanically complex water-clock some four metres high and about three meters deep, in which all sorts of things happen at each hour"[5]. See figures 127, 128.

[5] Quoted in Hill, Donald (1998) *Studies in Medieval Islamic Technology: from Phlio to al-Jazari-from Alexandria to Diyar Baker*. p. xv.

Figure (127)

The modern reconstruction of al-Jazari's first clock at the Science Museum in London. (Hill)



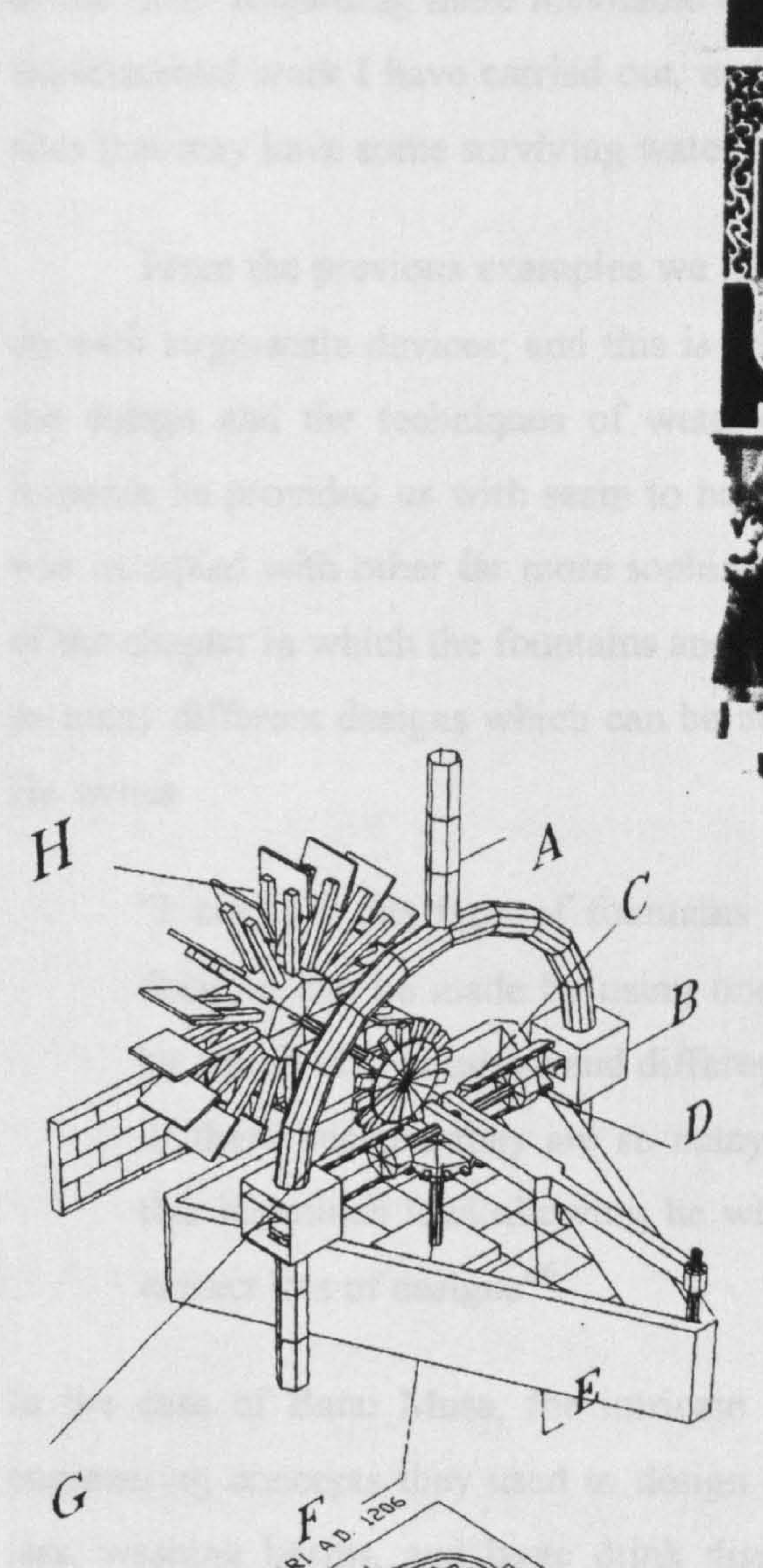


Figure (128)

A reconstruction of the drawing of al- Jazari's double-acting pumps exhibited in the Science Museum in London. (Hill)

It is hard to provide a fair judgement on the work of each engineer, giving specific details of the fountains described. The lack of technical data in the engineering volumes we posses stand as a major defect to make a scientific comparison between the works of the engineers. The second defect we are faced with is that we have no in our hands any archaeological artefacts that would provide us with a great deal of information about the technique, the materials and the scale of the fountain machinery of the time. Regarding these inevitable defects my judgement is based mainly on the experimental work I have carried out, and also on historical reports and architectural sites that may have some surviving water-features.

From the previous examples we may gather that al-Jazari mainly concentrated on such large-scale devices; and this is why he dedicated almost half of his book to the design and the techniques of water-clocks. Therefore the six designs of the fountain he provided us with seem to have been of a minor interest to him, since he was occupied with other far more sophisticated designs. Al-Jazari tells us at the end of the chapter in which the fountains and the flute devices are described that there are so many different designs which can be based on mechanical concept he introduced. He writes

> "I say that this type of fountains and flute devices, of which there are ten designs, can be made by using one unique and extraordinary ingenious idea, by which many designs and different shapes are made. I have not reported any of these because they are so many. However I will explain the principle of this ingenious idea allowing he who has interest in this science and craft to extract lots of designs"[6].

In the case of Banu Musa, the intricate design of their fountains was part of the engineering concepts they used to design about 87 models of trick drinking vessels, jars, washing basins, and large drink dispensers, which occupy almost their entire book. This is why Banu Musa's fountains, in comparison to those of al-Jazari, are

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[6] Al-Jazari Ibn al-Razzaz (3) Al-Jami bayn al'ilm wa l-Amal al-Nafi' fi Sina'at al-Hiyal. edited by A. al-Hassan. p. 436.

relatively small. I have based this judgement on experiments I have undertaken on the fountain-head designed by Banu Musa. Although it is hard to give an exact idea of scale unless a number of fountains are examined, the approximate size of the fifth fountain of Banu Musa is from 30 to 50 centimetre for the sphere that contains the machinery of the fountain. This of course dose not mean that al-Jazari was less capable of designing fountains in such intricate fashion than Banu Musa had introduced. The fact is that since al-Jazari was a highly skilled craftsman, besides being an inventor and a professional draftsman. He was therefore more aware of his own design and creative work. Yet in his book, he expressed his criticism of the interval timing of this particular fountain, No. 5. Hill was aware of al-Jazari's criticism and wrote that: it would not be safe to ignore al-Jazari's critical remarks.

In this regard we may safely infer that al-Jazari also had a tendency to simplify the mechanism of the fountains he devised which were, in a practical sense, designed according to the size and the scale of the surrounding environment, or more accurately the pools, in which they were erected. So al-Jazari's fountains must have been greater than those of his successor, Taqi al-Din, where the size of the pools were rather typical, which are evident in some surviving water-feature of the 16th century historical sites in Istanbul. Moreover, the biographical account on Banu Musa and al-Jazari provides us with some facts about the engineering tradition that is particularly associated with them. Al-Jazari informs us that he was in the service of the Artuqids Kings, and in the courts of whom he lived for 25 years. Therefore the judgement that can be introduced here is that since his designs were linked to that palatial environment, the exaggeration in the scale and lavishness of the designs are characteristics.

Yet, in Banu Musa's case, they were not directly connected with the royal court, they were more independent based; this is why the annual business income of the eldest brother Mohammed from Baghdad, Persia, and Damascus was four hundred thousand *Dinar* as reported by the biographer *al-Qufti*. From an engineering aspect, this means that Banu Musa were commissioned by a wide class of people, which in a way determined their engineering tradition of designing the fountain.

Taqi al-Din, on the other hand, was closer in his designs to al-Jazari than to Banu Musa. The fountains were operated by the mechanism of the tilting-bucket and the lifting-float, which are found in al-Jazari's work except that Taqi al-Din introduced the siphoning mechanism. Again we find that Taqi al-Din devoted the first chapter of his book to the design of different types of clocks; and the most significant of all is his description of the six-piston water-pump (see figure 129). Although Taqi al-Din and al-Jazari described a number of fine technology devices like fountains and trick vessels, their works on the technology of water-lifting machines and water-clocks were of paramount importance in terms of the innovativeness they introduced. We may infer that the size of the fountains in Taqi al-Din's work were relatively modest in comparison to the fountains of al-Jazari and Banu Musa, but it is again hard to give a specific scale.

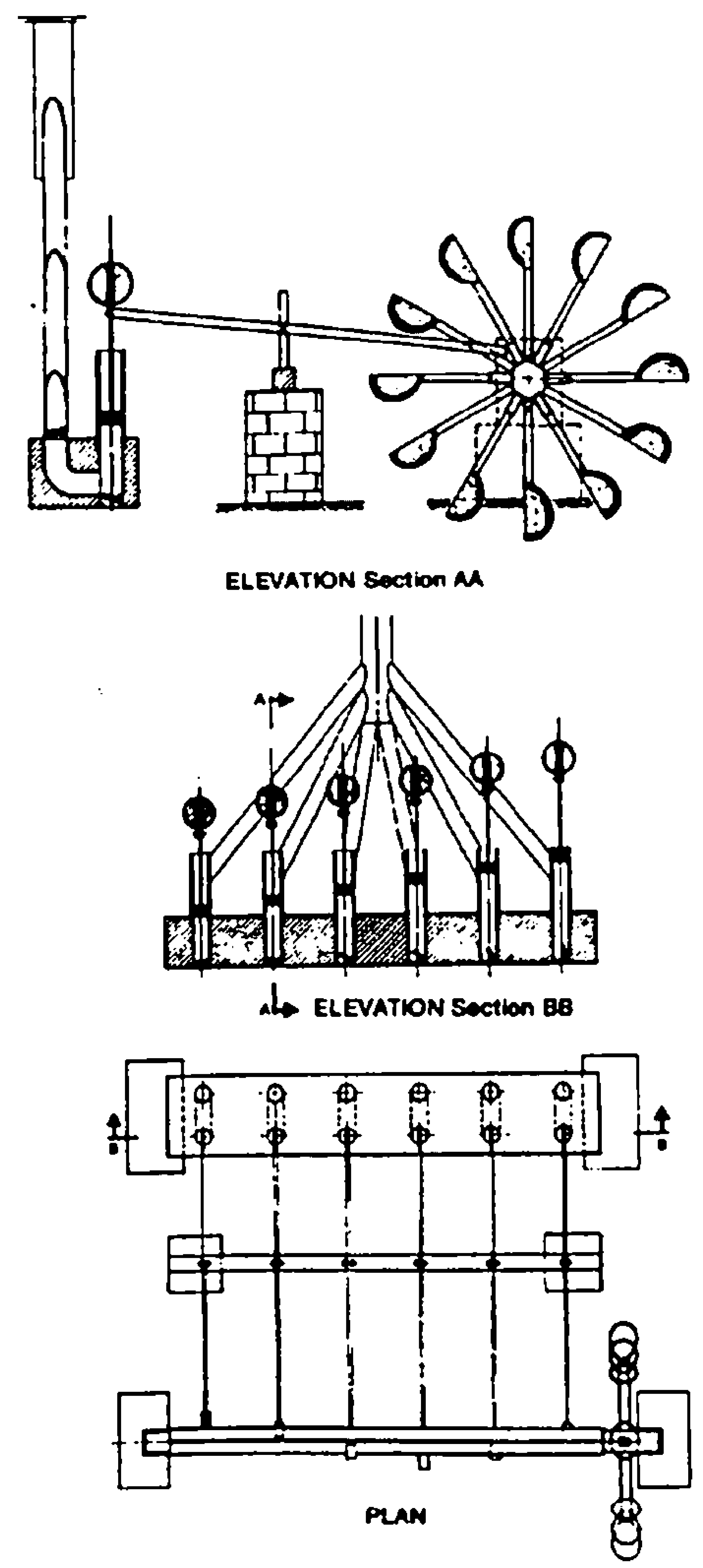
However, this assumption can be justified if we consider the hard job in applying the siphoning mechanism on such a large scale. This is also applicable to the fountain of Banu Musa if there was an attempt to scale-up the size of the fountain. Difficulties would have become apparent not just in the delicate mechanism of Banu Musa fountain, but also in the arrangement of its fountain-head, which I have come to judge from my experimental work.

Finally, we may safely come to the conclusion that all the mechanical concepts applied in Banu Musa's, al-Jazari's, or Taqi al-Din's fountains were, from a design point of view, designed in accordance with the size and the purpose they were set to serve. It may, however, seem to a certain degree rather difficult to make a fair judgement between the works of these engineers without taking into account the circumstances of their time and environment. However, nobody would deny the high status that Banu Musa occupied in the history of Islamic technology and engineering in which they surpassed their predecessors and stood as a challenge to their successors.

Figure (129)

Reproduction of Hill drawing of

Taqi Al-Din pump. (Hill)



Water in the Tradition and Culture of Islam

"If I were called to construct a religion
I should make use of water"

Water by Philip Larkin

The metaphors of water are supremely rich to the point of paradox. The comprehension of quietness and action of water in nature (seas, rivers, streams, waterfalls, and so on) as it rises up, splashing against things, cascading over surfaces, remaining still as the most pure and revealing agent, or falling into itself creates a sense of poetic motion in its manifold rhythms and colourful tones. Aside from any thing else water is the origin and the distinct symbol of life. Nothing escapes its influence, life in its entirety depends on water and nothing survives without it. Water like a primordial catalyst, pulls at a primitive and deeply rooted part of human nature. Besides being the source of life, water combines a vocabulary of power, comfort, fear, and delight. It is a symbol of purification in both the decomposition of life and its renewal. A depiction of pictorial catalogue of water phenomena would surpass the world's scenery to be complete.

Water is not just the genesis of life; it is the life-vitality in its spiritual and physical dimensions. The spiritual vitality of water is experienced not only by the people of the holy revealed books, but even by pagan civilisations, Buddhism and Hinduism, etc. In the Old Testament, as Charles Moore writes: water represents the quality of cleansing the soul as it washes the body. It symbolises, however, the path into spiritual life and the promise of eternal salvation. "*I will sprinkle clean water upon you and you shall be clean from all your uncleanness, and from all your idols I will clean you*".

The New Testament emphasis this spiritual quality, it reads "*a baptismal plunge in the river Jordan would purify the soul by washing away sins*"[1]

[1] Charles Moore & J. Lidz (1994) *Water and Architecture*. p. 20

In Islam water occupies a significant status; the term 'water' occurs in sixty-three places in the Holy Koran; moreover it appears in tens of places as rivers and springs, etc. The creation of water, as stated in Koran, was prior to the creation of the heavens and the earth: "*He it is Who created the heavens and the earth in six days and His Throne was over the water*" (Koran, 11: 7)

The relationship between water and vitality is a profound one. However, there is a subtle difference between life and vitality. Life is a structural characteristic, while vitality is a function of that characteristic. In a Koranic verse God Who is the creator of everything in the universe and beyond reminds us that water is the source of organic vigour, it reads:

> "*Do not the unbelievers see that the heavens and the earth were joined together before We clove them asunder, and We made from water every living thing? Will they not then believe?*" (Koran, 21: 30)

The meaning of this verse can be interpreted to be this: 'We have brought forth all living things from water'. Vitality, then has arisen from, and gained power from, water, since the term '*made*' refers to the act of empowering not to the act of creation, in this particular term. Recognition of this vitality is philosophically portrayed by the medieval renowned poet Abu al'la al-Mi'ari:

> We are like water...
> Which remains in its sources,
> Still-houses...
> Stagnant as time passes[2].

The vitality of water in Islam in association to man is subtly profound. Water plays a

[2] Quoted in *Al-ma' fi al-fikir al-Islami wa al-Adab al-Arabi*. By M. Abd al-Aziz Binabullah (1996) Vol. 2, p. 217, and translated by the researcher.

significant part in the daily ritual life of the Muslims. It is the gateway to the spiritual world and the messenger of spirits to the physical world. In Islam, water is the religion, and the religion is water. Some Muslim theologians introduced this interpretation, which has been derived from the verse in Koran:

> "*He sends down water from the skies, and the channels flow, each according to its measure: but the torrent bears away the foams that mounts up to the surface……… While that which is for the good of mankind remains on the earth*" (Koran, 13: 17)

The seventh-century theologian Mujahid interpreted this verse by saying that water is what remains on the earth and it that which is for the good of mankind. Upon this the author of Suk al-'aroos, al-Tabari, reports that according to Mujahid interpretation, God has resembled the Koran as water, while hearts as torrents[3].

Another beautiful Parable, explaining the nature of our present life. It reads "*The likeness of the life of the Present is as the rain which We send down from the skies by its mingling arises the produce of the earth*" (Koran, 10: 24) This intimate relationship between water and life, heaven and earth, and soul and body is the core of human existence and a sign of the act of the Creator and reaction of creatures. Water, in the Koran always appears as an evocative symbol that to make the man thirst to come closer to the perception of the Divine reality as the earth thirsts for water.

This mysterious phenomenon and inexplicable relationship between man and water has evoked man's thoughts in the culture of the world civilisations; however, in Islam this relationship has reached the zenith of its spiritual status. Schimmel suggests that perhaps al-Rumi, the renowned philosopher and mystic, has depicted the deepest and the most beautiful verse about the symbolic mystery of water, as he knew that man would never seek God unless he was attracted to Him in the first place[4]. In a

[3] Quoted in *Al-ma' fi al-fikir al-Islami wa al-Adab al-Arabi.* by M. Abd al-Aziz Binabullah (1996) Vol. 2, p. 198.

[4] This is quoted in *The water of Life* by Annemarie. Schimmel (1985). p. 9.

metaphoric sense, Al-Rumi, articulates: "When the thirsty seeks the water in the world: The water too is seeking the thirsty in the world"[5].

So the connection between the spiritual and physical world is immutable. In the Koran the spiritual is figured by the Canopy of Heaven, whilst the physical is figured by the earth. This has been stated as one of God's goodness, that reads: "*Who has made the earth your couch and the heavens your canopy; and sent down rain from the heavens*". (Koran, 2: 22) A beautiful portrayal of the spirit of this connection is conducted over the fountain by the tenth-century renowned poet Ibn al-Mu'tez:

Surging water...
in the heart of a garden,
a jewelled mist...
suspended around the fountain.

Once...
the elegant jet...
to sky is sent,
falling canopy-like...
is lavishly built.

Relentlessly...
attempting to reach the stars
desperate...
for its absent heart[6].

The mediating function of water symbolises the essence of the spiritual world between man and his Creator. It is a symbol of negation and humbleness of mankind

[5] Quoted in *The water of Life*, by Annemarie Schimmel (1985), p. 9.
[6] Quoted in *Al-ma'fi al-fikir al-Islami wa al-Adab al-Arabi*, by M. Abd al-Aziz Binabullah (1996) Vol. 3, p. 272, and translated by the researcher.

opposite to Almighty God. It also elucidates the passion of Divine-love that mystics have devotionally immersed into its world, conceiving the glory and sublime nature of God. Annemarie Schimmel explains that the question of the real depth of the Divine Sea has been posed by the mystics through which guidance is to be obtained by the disciples. As God can be seen as an "infinite ocean", how could an ocean fit into a small vessel? How could the Almighty be contained in the vessel of man's understanding and perception? They also introduced the idea that man emerges from the Divine source like a drop that ascends from the sea into a cloud, and then descends as a raindrop into its inborn element to be re-united with the ocean. The drop, however, can also be blessed by falling into the open mouth of an oyster and will become, then, a precious pearl, which is part of the ocean and yet distinct from it.[7]

The symbolism of water is so pregnant of powerful meanings that will take an entire project to investigate, which this thesis is not intended to. In Islam water is a gift from God a token to the omnipotent, omniscient and omnipresent of Divine. Many verses emphasise water, not only because of its very necessity for the maintenance of life and the cultivation of land, but also due to its significance in ritual purification. *"And He caused rain to descend on you from heaven, to clean you therewith, to remove from you the stain of Satan"*. (Koran, 8:11) Although, water in this verse symbolically represents the return into primordial state of the Muslim, which is also practised in the act of daily ablution, it symbolises the descent of revelation.

Evil makes of the souls of men what drought makes of land: it kills life, beauty, and fruitfulness. God's Word in the spiritual world has the same wonderful effect as rain has on barren land: it gives life, beauty, and fruitfulness. This is stated in a powerful meaning verse that reads:

[7] Quoted in *The water of Life*, by Annemarie Schimmel (1985), p. 6.

"And (further), thou seets the earth barren and lifeless, But when We pour down rain on it, it is stirred (to life), it swells, And it puts forth every kind of beautiful growth (in pairs). (Koran, 22: 5)

This verse conveys the miracle of water by which the flourish of life on the earth as well as its ruination is in likeness to the purification and deterioration of the spirit. Thus the perceiving of life-giving water is one of the views that makes the spirit and the senses equally happy.

Water has been profoundly celebrated in Islamic culture. Muslims call rain 'mercy'. It is mercy (rain) that descends from the most merciful, God, to revive and bring life to all living creatures on the land, exposed to mercy. One can easily understand how much feeling develops when living in dry and arid climates. The revival of life and its celebration has been practised since the advent of Islam until the present time.

The story of a miracle revival goes back years after the flood when Abraham settled his wife Hagar and his little son Ishmael in an empty valley-that later became the city of Mecca. As Ishmael began suffering the torments of thirst, Hagar desperately ran to and fro with uplifted hands looking for water in the valley, always across the same stretch between two low hills. It is in remembrance of her despair that all pilgrims to Mecca run seven times between these hills, crying out 'mercy' as once she did. Then a stream of water gushed out- resembling the first 'natural fountain' in the culture of Islam- as the angel Gabriel struck the ground. This, pure water is nowadays drunk by all pilgrims as it was in the past.

In Islamic literature, Arabic in particular, documentation of poetry and prose are found that express powerful reflections portraying the colour, the movement and smell of water as well as the beauty of fountains and water-wheels.

About the smell of water AL-Jahiz in his famous book 'al-Bukhala'a' reported the story of a mother who advised her daughter in the wedding-day by saying:

"Let the water be your best perfume"[8].

Another deep meanings can be reflected upon these words; the purity of water, for example, can be derived beside the metaphor of its smell, which has been beautifully articulated in other expression that reads:

"Pure water...
its secrets revealed,
pool-stones lucidity...
appeared"[9].

The colour of water has been another striking property that ignited the poet's spiritual flame; and upon which reflections are expressed:

"Glass-water...
Is as blue as the sky,
A spring...
is as bright as the sun's eye"[10].

Another reflection upon the colour of water that beautifully reads:

"Water...
is radiant as a Candle-light,
like tears...
transparently bright"[11].

[8] Quoted in *Al-ma' fi al-fikir al-Islami wa al-Adab al-Arabi*, by M. Abd al-Aziz Binabullah (1996) Vol. 2, p. 207, and translated by the researcher

[9] Quoted in *Al-ma' fi al-fikir al-Islami wa al-Adab al-Arabi*, by M. Abd al-Aziz Binabullah (1996) Vol. 2, p. 207, and translated by the researcher.

[9] *Idem.* (translated by the researcher)

[10] *Idem.* (translated by the researcher)

[11] *Idem.* (translated by the researcher)

Also we find poets who have indulged themselves in the enchanting movement of water. Here the poet is giving a prescription to all those who seek refuge of the stressful life around them in which the spirit of water is the ultimate remedy, he writes:

"Feeling bored...
or sick...
of place.

Treat your soul...
travel...
at constant pace.

Be like water...
flowing...
an eternal race.

Stagnant...
You will be...
if you do not embrace"[12].

Furthermore, the water-wheel, in the history of Islam has been privileged with poetic expressions as it calls forth the imagination of poets by its rejoicing sound which evokes their spirits. Ibn Zafer tells us that one-day he and his friend were strolling by the Nile River where in a garden there were two water-wheels revolving on a well. Our hearts were deeply indulged as we have been watching them and listening to their moaning sound, he says. Then it was a spontaneous reflection from both of them upon the wheels. He articulates:

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[12] Quoted in *Al-ma'fi al-fikir al-Islami wa al-Adab al-Arabi*, by M. Abd al-Aziz Binabullah (1996) Vol. 2, p. 261, and translated by the researcher.

"A water-wheel...
moans as a mourning mother,
yet, no sadness does it suffer.

The wheel spills water like tears,
yet, flourishing flowers...
flourishing trees.

Revolving pots (star-like)...
round the orbital wheel,
infusing our souls...
filling hearts with zeal.

A pot raises...
and another fades away,
like the orbit...
revolves night and day"[13].

Thus it is not surprising that Muslim poets and mystics were preoccupied by the various manifestations of water. They depicted their perception of water in such a lofty and spiritual way. Although in pre-Islam Arabic sources water-poetry always connected with the natural phenomenon and the honour and the pride of offering water to pilgrims on their way to Mecca, this respectively has continued later in Islam, but in rather a poetic and philosophical way. From a historical point of view, water-features, however, were hardly existed in pre-Islam Arabic architecture. Therefore, until the last years of the first-century Islam (7^{th} century AD) the architectural-water-poetry was seldom present. As the Arabs came face to face in the lands they ruled with existing civilisations, Persia and Byzantium; the transformation of Islamic art and architecture took place. Consequently, the palatial life of the rulers in their

[13] Quoted in *Al-ma'fi al-fikir al-Islami wa al-Adab al-Arabi*, by M. Abd al-Aziz Binabullah (1996) Vol. 3, p. 265, and translated by the researcher.

palaces brought forth the notion of the Islamic garden, and courtyards where water-features reached their climax of beauty and lavishness. The most remarkable surviving examples of those Islamic water-features are the medieval fountains of Alhambra. The occupational metaphors of these fountains were highly extolled in poetic composition.

From many examples of water-poetry we can experience the expression of the poet, who perceived the aesthetic and spiritual qualities of water gushing out of the fountain of Lindaraja in Alhambra. The following poem is inscribed on the bowl of the fountain. It reads:

> "I am surely the ark of the water that appears...
> To the people, visible not concealed.
>
> A grand sea whose shore is...
> of the most marvellous and selected marble.
>
> Its water is like melted pearl that flow in hail ...
> 0, what a great wonder.
>
> The water in me is translucent so that I am...
> sometimes, not hidden from your gaze.
>
> So that I and what I contain...
> of the water spring in the bowl.
>
> Are like a piece of hail, some of it..
> is melted, and some is not.
>
> As if the gardens were covered with water, you will think...
> that I am a ship that sprout all shooting stars.

As if the visible part of me is a shell...
that extruded the essence of all those gushing hail-stones.

I resemble the palm of the Knowledgeable (craftsman)...
When it is spreading the gems."[14]

N. Rabbat introduces three inferential metaphors from these poetic expressions. Firstly, the visual confusion of water is reflected between solid and liquid. Secondly, the contemplative function of water, an artistic water-sculpture with ultimate beauty to be meditated upon. Thirdly, the aesthetic integration of water within the context of architecture[15].

Water, as we gather has played a significant role in secular and ritual life of Muslims, it vitally meant life and thus life has the full meaning of water. Incorporating as it does religious, poetic, aesthetic feelings and meanings of the highest order. Any study that attempts to understand and illuminate the path trodden by engineers in the development of the fountain must take this as its starting point.

So how could one not appreciate a peaceful water-feature that placed in the heart of a courtyard of a building that brings life to the spirit and senses in such a manner as the torrent sweeps away all that is lifeless and dry?

[14] Nasser Rabbat (1985) *The Palace of the Lions Alhambra and the Role of Water.* pp. 71, 72.
[15] *Ibid.* p. 72.

The Fountain in the Art and Cosmo-Aesthetics of Islam

"If the doors of perception are cleansed,
every thing would appear as it is infinite".

William Blake*

Water, this life-giving substance, appears over and over as a common thread woven through the culture and religion of every nation and all civilisations known to history. The world of water, has primarily, embraced every culture. As a mediator, on the other hand, water played a major role between people and culture, since communication with the past, environment, religion, or even myths has been a natural need of human being. Man persistently sought a symbolic representation of his culture within his own world. So in his dwelling, he devised a concept of design that to introduce water into architecture. The meaningful expression of water with its timeless potential in the architectural environment led man, the culture in general, to treat the fusion between water and architecture with care and creativity.

The combination of water and architecture engages people by letting them see, hear, and touch innumerable exquisite experiences. Ultimately, sight, sound, and contact are significant determinants at the inception of a building. Water serves as the lifeblood for meaning in architecture, through which the whole scenery of water manifestations and its spiritual meanings is called to mind regardless of how small the amount of water is. In pursuit of this, architects tried to communicate ideas by employing materials, manipulating forms, and bringing in actions of water. Such a creative setting enables the observer to perceive and apprehend more about the culture and the art that stands behind the scene.

Art and culture may be conceived as a pair of spectacles that we need to wear so that the world can seem vividly distinguished and real. Similar observations led to a belief among many classic Islamic writers that a work of art is always something more than it appears to be. It is in likeness to 'mystical' overtone concealing a

* From "The Marriage of Heaven and Hell: A memorable Fancy"

profound inner meaning beneath its apparent harmonious form that is virtually articulated in any perfected work of art. The 12th century eminent philosopher and mystic al-Ghazali perceived this that children and animals can experience form, but only the eye of the heart can perceive the "inward form"[1].

Of course, such a statement brings us to the exploration of the transcendental dimension of this 'inward form' in its entity as well as in its individual aesthetic qualities, which are our main interest. As far as these aesthetic qualities are concerned, Islamic art in general appears to be totally coherent and integrated. Religious values, ethical qualities, socio-environmental conditions, cosmic law, principles of science, and other domains of knowledge all are the formative components of its overriding aesthetic. However, each one of these components bears a certain individual aesthetic quality. It is a reflection of God's beauty according to prophetic tradition that "God has inscribed beauty upon all things". So Islamic art and its aesthetics are not autonomous in any sense of the word. It is as John Renard writes an art for the body, of the spirit, by people who have perceived the traditional thought that, "God is Beautiful and He loves Beauty", and kept it alive.[2]

Every visible form that emanates in the unseen world, al-Rumi writes, never escapes the Divine Beauty, which is reflected in all things created. God is Beauty itself, and from the "mine of loveliness" that is His abode, "filings of beauty" become the prize possession of all creation.[3] Thus the experience of Holy, as Rudolf Otto has pointed out, is in several ways analogous to the experience of the Beautiful.[4]

In a reflection on the theory of Islamic aesthetics, O. Naseem writes that God, the Absolute, is inscribed upon the infinite continuum; this in turn presents the inscriptions of infinite acts and conveyances in the finite human creation of an art work.

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[1] Quoted in *God is Beautiful and He Loves Beauty*, by John Renard (1983) p. 99.
[2] *Ibid.* p.108.
[3] *Ibid.* p.99.
[4] *Ibid.* p. 95.

For, the portrayal of infinite patterns in the Islamic works of art always articulated, this appear to flow upon eternal rivers in the pursuit of their sources among the sublime.

Thus the extension of these infinite patterns beyond the finite plains of vision become evident. So the seeds of continuous infinities upon the impressionable unconscious and conscious mind of the observer are sown. In their continual projections upon the human soul, these realisations and sensations are contrived of infinity, and provide the real and exalted aesthetic experience for which each human heart yearns. The intercommunications of all these infinities are drawn from the Absolute, the Antecedent source of all Islamic art. It is the art that expresses nothing but the pure submission to the Absolute One God. This can be derived from God's word; in the Koran, 13:28 God says: '*Those who believe, and whose hearts find satisfaction in the remembrance of God: for without doubt in the remembrance of God do hearts find satisfaction*'.[5]

This interpretation of aesthetic theory proclaims that in Islam all is God, all law, all beauty, all art, all writing, and every gesture. Here the sense of unity and full integration of both finite and infinite worlds, which signifies the real essence of Islamic art and architecture are delivered. Yet we find that the systematic 'order' of the perpetual and infinite patterns in the art of Islam in conjunction with the 'coherent' correspondence between the visible and invisible are the conveyer of this sublime 'unity'.

G. Engler defines these three aesthetic concepts as order, coherence, and unity. He writes that the assumption that the natural world contains regularities and structures provides the meaning of order in science, and it is the task of science to capture them, by formulating the laws of these properties, which will bring them in concordance with nature, and order will then follow. Yet well-grounded generalisations of these laws fulfil their purpose and consequently form a fully coherent system. Unity may then be considered as the ultimate objective of achieving the greatest coherence and explanatory power of a theory. The expression, therefore,

[5] Omer Naseem (1998) *Towards an Islamic Aesthetic Theory*. p. 80.

of the essence of the perception of an orderly world that can be comprehended by the human mind is through these concepts of the aesthetic: order, coherence and unity.[6]

- **Perception of Aesthetics**

The perception of this unity, as we gather, is the gateway to the comprehension of the seen world and the unseen world, the world of soul and the world of spirit, which is in a way a definition of the fusion between art and religion. Apostolos-Cappadona identifies this fusion as one of five relationships between art and religion, by which they became fused into a single identity, making it impossible to distinguish where the art begins and the religion ends.[7]

The act of aesthetic perception in Islamic art is bound to an abstract symbol, which is analogous to superior forms or signs through which the aesthetics of meaning and pleasure are conveyed. Yet it is the fact that through analogy our daily experience of the world is enriched with layers of inter-related meanings. It is a process whereby we attempt to learn about, describe, or provide an insight into less customary facts by means of comparing them to more customary ones. This puts emphases upon the fact that the human imagination has no access to the spiritual realities of the invisible world, which leads to comprehension of the nature of spiritual realities except through the grasp of mediation over actual examples.

The eleventh-century theologian and philosopher al-Ghazali highlighted the fact that all sensible existents are symbols representing or embodying spiritual realities. In his *Ihya Ulam al-Din*, he writes that: "The visible world was made to correspond to the invisible world and there is nothing in this world but is a symbol of something in that other world".[8]

[6] Gideon Engler (1990) *Aesthetics in Science and in Art*. p. 30.
[7] D. Apostolos-Cappadona (1996) *Religion and Art*. p. 140
[8] Quoted in *Analogy & Symbolism: An Approach to the study of Traditional Islamic Architecture*. by Samer Akkach (1992) p. 87.

Here, it is quite clear that symbolism is the key component of religious awareness, which strives to grasp certain spiritual realities by means of physical examples. These physical examples or existents are rendered as symbols through the act of analogical relationships with spiritual realities. This analogy between the physical and the spiritual worlds is the basis of symbolism, which evolves from intuitive understanding to communicate knowledge. It is the fountain, the physical symbol, from which an abundance of symbolic meanings can be derived as a thread of water is projected up into the sky.

- **The Fountain and Symbolism**

Symbols mediate ultimate reality through things or actions. Yet symbolism casts a new value to these things or actions by virtue of this mediating function, causing no effect on their own proper and immediate value. Moreover, this mediating function prepares, as it were, these things and actions to receive the qualities of the higher reality for which they mediate. As far as the fountain is concerned, it is a representational example of such qualities, which is to be delivered upon such symbol by a mediating function of its action.

The fountain, on the other hand, as an architectural symbol in Islam imbues human existence with significance by delivering profound qualities and spiritual meanings. These qualities are delivered in a number of symbols, for example, a link between the temporal world and the celestial world is created through the perpetual projection of a crystal thread of water into the sky. This symbolises the act of purity; ascending from the heart of a courtyard in a form of prayer, absolute submission to God embedded in a devoted Divine-love. It also symbolises the act of mercy descending in a form of limitless Divine gestures, that cheers and rejoices the spirit; as well as brings life to lands and creatures who yearn for water. These correspondences between the two spheres of reality are the very nature of symbolism in Islamic aesthetic. In fact, those symbols of the inferior spheres are perceived as representing those of the superior, the physical representing the spiritual, and the seen world representing the unseen world.

Samer Akkach defines the traditional Islamic view of symbolism by saying that the notion of symbolism in Islam reveals a hierarchical view of the universe. Form and meaning, the signifier and the signified, are bound by an ontological relationship, whereby the very mode of existence of the signifier is determined by the higher reality being signified. This means that a form communicates the meaning it embodies wherever it is manifested. It perceives our sensible world merely as a shadow of the spiritual world, which is an intermediate sphere between our shadowy world and the source of light, God. Everything in this world according to this perspective is a symbol. Yet it is a manifestation or a shadow of a higher Reality in its own right. Therefore, a symbol is primarily unreal, but it appears to be real since it acts as a reflection upon the Real.[9]

Symbolism in the art and architectural domain of Islam is based on an analogical interpretation between the shaping of the world and the shaping of architecture. The traditional Muslim architect in an attempt to intellectualise the unmanifest meanings God has given to cosmic forms; embodied these formless meanings in architectural forms. Therefore, the architectural form; city, mosque, house, palace, or garden was conceived as a miniature cosmos. Built-forms accordingly reflected upon the design of the cosmos that God had fashioned, so that they revolved around the development of the sacred geometry of the cosmic structure, and are a crystallisation of the cosmogonic process.

The adaptation of the sacred geometry in Islamic art and architecture as analogical symbols to express the principles of the cosmic manifestation, were revealed to architects through the mediation upon the cosmic forms. Ikhwan al-Safa, *Brotherhood of purity*, the tenth century group of philosophers states that:

> "The study of sensible geometry leads to skill in all the practical arts, while the study of intelligible geometry leads to skill in the intellectual arts. This

[9] Quoted in *Analogy & Symbolism: An Approach to the study of Traditional Islamic Architecture*. by Samer Akkach (1992) p. 88.

science is one of the gates through which we move to the knowledge of the essence of the soul, and that is the root of all knowledge"[10].

The origin of both the sensible and intelligible geometry is the point, the very centre, of all manifestations. It is the essential characteristic concept of all traditional Islamic art and architecture. This was clearly reflected on the plane of the early cities in Islamic states, and on the secular and the religious buildings throughout the Islamic world. It is the centre, the intelligible point, that embodies the non-worldly Principle of space and time, which is the focal point wherein all virtualities of spatial extension and temporal duration are eternally present. Keith Critchlow articulates this in his book 'Islamic Patterns: An Analytical and Cosmological Approach'. He writes:

> " The manifestation of an action, object or thought (if can be defined) necessitates a point of origin or departure, in relation both to the manifestation itself and the person who is conscious of its emergence. The point of the emergence does not necessarily reveal its causation either in the field of its emergence or in the mind of the viewer. In the mind the point represents a unitary focus of conscious awareness; in the physical world it represents a focal event in a field which previously uninterrupted".[11]

S. Akkach reveals more about this as he quotes the philosopher Abd al-Karim Al-Jili from a manuscript he had access to, in which he writes that the point, in reality, is far from being perceived by sight. It is indivisible in itself, although everything in the physical world is divisible as being manifested by it. Therefore what is perceived now is the sensible point in an expression of its reality, that is determined in it being a single or an indivisible substance. This sensible point is defined by the tiniest spatial entity whose repetition produces a line, the repetition of which produces a plane, and the repetition of which produces a volume.

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[10] Quoted in *Islamic Patterns: An Analytical and Cosmological Approach*. by Keith Critchlow (1993) p. 7.

[11] *Ibid.* p. 9.

Even though the sensible point is infinitely small, it is conceived as a spatial point that has dimension.[12]

The intelligible point, on the other hand, as S. Akkach adds, refers to its principle of dimensionless and indivisibility which stands beyond the boundaries of spatial conditions. Yet the intelligible point not only transcends space but also normal comprehension. Although mind's grasp of this point could be affirmative, our constant failure to attribute it to any quality is evident.[13]

- **The Fountain and Cosmo-aesthetics**

We gather from the previous section that the centre was perceived in the tradition of art and architecture as the terrestrial sign of the heavenly beam. It forms an imaginary cosmic pole that penetrates the horizontal expanse of earth, connecting the celestial, and the terrestrial worlds. The cosmic pole is expressed in an architectural form by an imaginary vertical axis. This axis connects the higher centre of a building to a higher status. For example the apex of a minaret that directs the soul towards heaven is a constant reminder of the higher Principle, God; another example is the apex of a dome which itself symbolises the uplifted roof, heaven. This is also represented by an imaginary line that links the centre of a whole form to a higher centre. In a city, for example, in which a mosque is to be its centre, or the centre of an open courtyard in which a fountain shoots up water creating a crystal line; the expansion of these symbolic lines from their form's centres correspond to the centre of heaven.

Ibn Arabi, the thirteenth-century eminent mystic and philosopher, elaborates on the immutable axial relationship between the terrestrial centre and the celestial centre. He writes that Ka'ba, House of God (the holy shrine in Mecca), has its celestial counterpart, *al-Durah* (heavenly house).

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[12] Samer Akkach (1995) *In the Image of Cosmo Order and Symbolism in Traditional Islamic Architecture*. part 2. pp. 91, 92.
[13] *Ibid.* p. 92.

This *al-Durah* is placed in its stationary location in the seventh heaven. God has made these heavens firm and stationary; they are to us as the roof as is to the House, and that is why, in Koran, heaven is called the uplifted roof (*al-Saqf al-Marfu*).[14]

This vertical axis, however, signifies the channel of ascent, which leads upward penetrating the terrestrial boundaries of the physical world, transcending beyond its limits and confined to the limitless and the infinite. It is as well an exposition of the channel of descent, where the temporal world receives higher Realities as they flow downward. It is a manifestation of the finite to the Infinite and the mortal to the Eternal. The cosmic axis is the line of communication between superior and inferior, heaven and earth; and acts as a thread of the continuity between the Divine, the signified, and the symbol, the signifier. This can be perceived in a fountain, its vertical jet creates an axis, an imaginary pathway of ascent and descent. This crystal axis of water upsurges from the terrestrial, finite world, representing the act of ascends. Then it falls back plunging into the basin of the fountain, the individual finite world, in a form of stream of jewel-like water-drops, representing the act of descent, flowing down from the celestial, infinite world, to finite world. The renowned medieval poet, Ali Bin al-Jahm, exalted these metaphoric acts of the fountain in a poetic expression; he writes:

> "A fountain...
> cleaves the sky,
> never gives up...
> or would die.
>
> See it...
> ascending to heaven,
> descending back...
> with tales...
> of now and then"[15].

[14] *Ibid.* p. 95.
[15] Quoted in *Al-ma'fi al-fikir al-Islami wa al-Adab al-Arabi.* By M. Abd al-Aziz Binabullah (1996) Vol. 3, p. 270, and translated by the researcher

The cosmic axis according to many traditions is associated with the idea of the centre of the world where heaven and earth meet. The position of Ka'ba, the Holy shrine in Mecca, was seen as the terrestrial centre because it was viewed as corresponding to the position of the Pole-star, which was seen as the celestial centre. The centrality of the Ka'ba was traditionally proven not only because of its relation to the pole star around which all stars orbit, but for its juxtaposition to the mount of *Abu Qubays* from which, according to prophet's traditions, the whole planet expanded and formed to its shape. This is evident that the Ka'ba stands at the navel of the earth as the Pole star stands stationary above it. David King writes that:

> " In 1989 a remarkable world-map centred on Mecca came to light (...it was) originally fitted with some kind of universal sundial. Some 150 localities between Andalusia and China are marked and named. The highly sophisticated cartographical grid [...] is conceived so that one can read the direction of any locality to Mecca from the circumferential scale and the distance to Mecca [...] from the non-uniform scale on the diametral rule"[16].

King believes that in Islamic cartography there is no parallel to these maps, they are without doubt distinctive in the history of cartography; and indeed, there is no evident of any European influence. Yet, it was thought that, prior to the rediscovery of the first map in 1989, the first person to construct a world-map centred on Mecca was the German historian of Islamic science Carl Schoy. From this map he published in 1920 one could read off the Qibla[17] and the distance to Mecca (see figure 130)[18].

This tradition as King reports that " research on the development of this remarkable tradition of Mecca-centred world-maps is currently in progress".[19]

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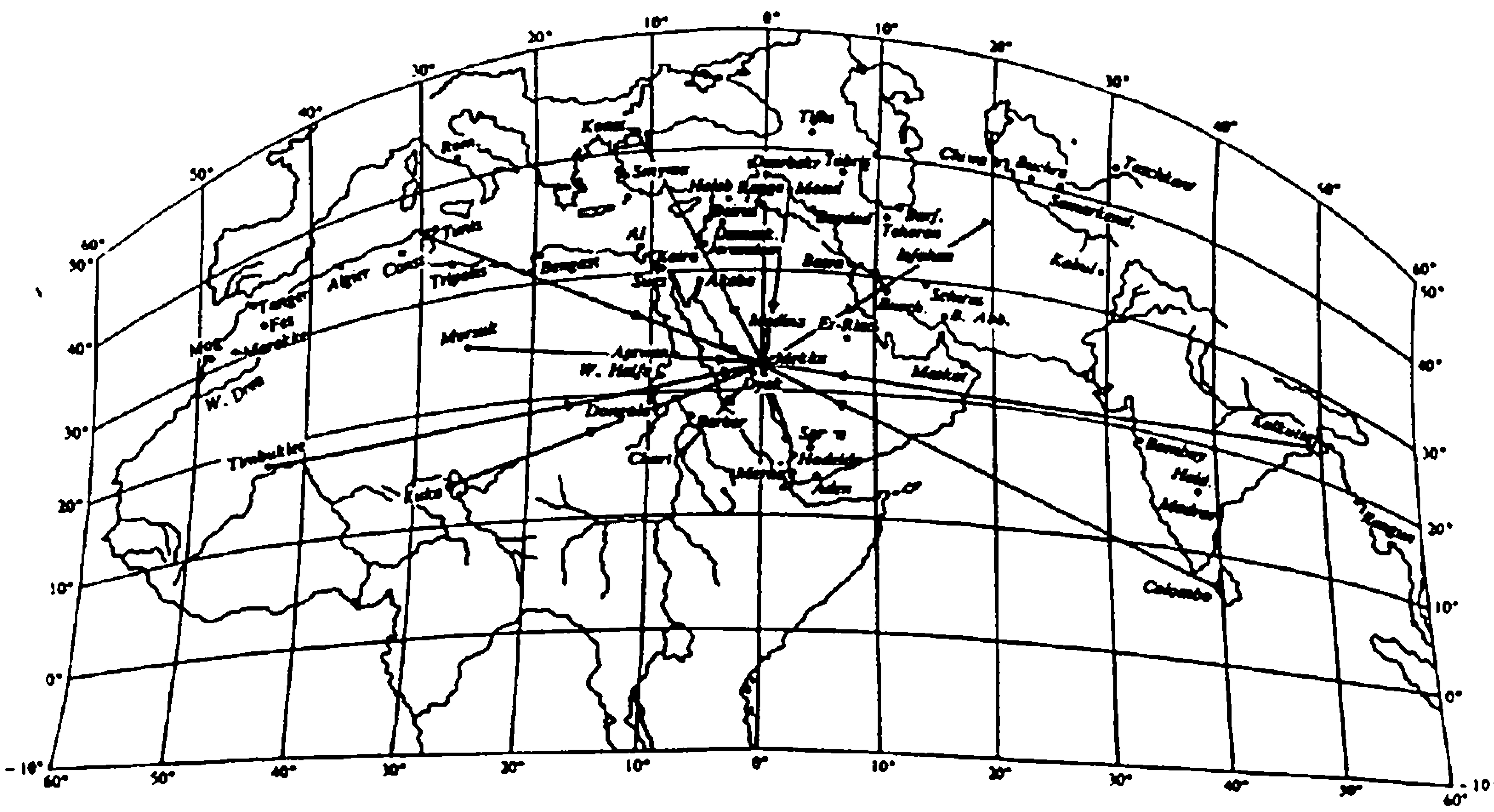
[16] David King (1998) *Astronomy and Islamic Society: Qibla, Gnomonics and Timekeeping*. p.150
[17] The direction towards the Holy shrine in Mecca which all Muslim must face in their prayers.
[18] David King (1998) *Astronomy and Islamic Society: Qibla, Gnomonics and Timekeeping*. p.151.
[19] *Ibid*. p. 153.



A world-map preserving direction and distance to Mecca, published by Carl Schoy, c. 1920

Figure (130)

The Ka'ba itself is astronomically aligned and what culturally was known to the first generations of Muslims as a true fact, this is why they used astronomical alignment in order to face the Ka'ba when they were far away form it. King affirms that medieval texts imply that:

> "The major axis points towards the rising of the star Canopus, the brightest star in the southern sky, and that the minor axis points towards midsummer sunrise. These two directions are roughly perpendicular to the latitude of Mecca. Modern plans of the Ka'ba and the surrounding mountains based on aerial photography essentially confirm the information provided by the medieval texts"[20]

[20] David King (1998) *Astronomy and Islamic Society: Qibla, Gnomonics and Timekeeping*. p.130.

The tenth century group of philosophers, 'Ikhwan al-Safa', elaborated on the notion of centrality in a Cosmo-philosophical interpretation, they wrote:

> "The House of God [Ka'ba] in the middle of the Holy Mosque, the Holy Mosque in the middle of the Sanctuary, *Mecca*, the Sanctuary in the middle of al-Hijaz, al-Hijaz [region] in the middle of the Islamic countries. It is in the likeness of the earth in the middle of the atmosphere, the atmosphere in the middle of the lunar sphere, the lunar sphere in the middle of the celestial spheres. And those who pray in the horizons oriented towards the House are in the likeness of the planets in the spheres, their radiations are directed towards the centre of the earth. And the orbiting of the heavens with their planets around the earth is in the likeness of the rotation of the circumambulants around the House (Ka'ba)"[21].

The House of god, the Ka'ba, in its pivotal position to the whole world imposes the notion of centrality in Islamic spiritual cosmology. The physical orientation towards the direction of the Ka'ba was symbolically introduced to every Islamic architectural form, whether it was a mosque, house, garden, or even a sub-form. This led to the creation of the notion of what I may describe it as a micro-cosmo-architectural-form. This can be seen, for example, in a courtyard, in which the fountain occupies a pivotal location towards which all elevations of the building were oriented. It is in the likeness of the elevation of the worshippers lining up perpendicular to the radius of the Ka'ba. Similarly the centrality of the fountain in a courtyard acts in a symbolic sense as a gravitational point of all its surroundings. It is in a way a reflection of the very characteristic principle of liturgical prayer in Islam, in which the lining-up of the worshippers is in a radial rather than a processional manner.

[21] Samer Akkach (1995) *In the Image of Cosmo Order and Symbolism in Traditional Islamic Architecture*. part 1. p. 91.

In his article 'Cultural Pluralism and Technilogy' YI-FU Tuan beautifully summarised the notion of the evocative symbols in the context of religious practice in correspondence to human experience. He writes that rituals are a technique, which drive meaning out of the common circumstances and daily experiences. A whole, almost manifest world can be called into existence by ritual gestures and evocative words.[22]

In the pursuit of such symbolic meanings, Muslim architects sought every means of technique to create forms of analogies to act as symbolic mediators. Domes, minarets, courtyards, and other architectural elements were conceived as cosmo-spiritual symbols. In the following chapters we will experience one of the ubiquitous symbols in both the sacred and secular architecture of Islam, which is the fountain. It is the fountain as we have seen that occupies the very heart of courtyards and gardens as the hub around which the building masses gravitated; with all elevation orientated towards the vertical symmetrical axis of the courtyard marked by the fountain's jet. We have seen as well how that the fountain emerges like a precious thread interwoven with the fabric of the architectural compositions, linking and combining a manifold of elements. Here also, in this splendid setting, is an image charged with strong spiritual values, aesthetic qualities, symbolic meanings, and cosmological connotations.

[22] YI-FU TUAN (1989) *Cultural Pluralism and Technology*. p. 273.

The Fountain in the Context of Islamic Architecture

Therefore in outward form...

thou art microcosm.

While in inward meaning...

thou art the macrocosm.

Jalal al-Din al-Rumi*

Whatever the culture is, the need for dwellings is a basic fact. Although it is a physical process that dominated by needs and desires, it is in Islam an aesthetic act. It entails a communication between nature and culture through a sequence of creating and manipulating. Moreover, it is the making of and caring for a place, through which the unification between the nature and construction, individuals and societies that reflects their own sense of identity, sense of unity, their needs, values, and dreams. Also it manifests the sense of contemplation that to be derived from all formed shapes in order to articulate their meanings, which contain the aesthetic experience of dwelling; although, from a functional point of view, these architectural forms were erected from necessity and to sustain a moral life, not merely for show.

These experiences gained are based on two main communicative values. The prominent philosopher and socialistic theorist Ibn Khaldun (1332-1406) addressed these values. He determines the first value that literally imposed the sense of the 'unified coexistent' between nature and dwelling, which was primarily to construct responsive architectural forms against the climate. The 'sense of the place' through this process was to be practised, on which the second value is founded. This is the 'sense of identity' that was displayed in the wealth, power, and the paternalism of the rulers through which architecture was engineered through the use of geometry, intricate decoration, sensational water-features, poetic inscription, monumental scale, and fine craftsmanship.

* A thirteenth-century prominent mystic and philosopher, his poetic work *Mathnawi* is the most celebrated one.

Anne. Spirn writes that "The understanding gained through this sense of unity, sense of identity, and sense of place are revealed in the manner in which we dwell. We are what we build and, in that building, we come to know who we are"[1].

For, a synthesis of a specific Muslim way of life can be seen through an architectural form whether it constitutes a complete composition or represents part of it; and as such still considered as a most complete artistic way of expression. A courtyard, by way of illustration, forms an individual unit, in which a fountain is symbolically and functionally characteristic, although it in the same time constitutes a distinctive part of the whole structure.

In the previous chapter we have experienced what Muslim gave paramount concerns to the concepts of centre and periphery and therefore they so tended to reinforce the integrity of the enclosed space. This tendency caused the enclosed space in both the secular and the sacred buildings to become the eloquent symbol of paradise built along with comfortable shelters. It is a refuge, a visible heart in the form of courtyard, which potentially breathing in cool air, by the virtue of its fountain, and exchanges it back as a warm air. J. Tonna frames out this artistic and spiritual scenery: " we inhale luminous, cool air, and our respiration is a prayer, as is the beating of our heart"[2].

Ernst Grube's observation on the symbolic and aesthetics characteristics of Islamic buildings led him to describe Islamic architecture as a "hidden architecture". He articulates his view that the focus on the enclosed space, on the inward as opposed to the outward, or to the general exterior articulation of a building, is one of the most striking characteristics of all Islamic architectural monuments.[3]

The emphasis on the typology of the enclosed space, interior orientation, in Islamic buildings was not confined to a particular type of architecture; it was present in the buildings of both secular and religious architecture.

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[1] Anne W. Spirn (1988) *The Poetic of City and Nature: towards a new Aesthetic for Urban Design*. p. 110.
[2] Jo Tonna (1990) *The Poetic of Arabic-Islamic Architecture*. p. 196.
[3] Samer Akkach (1995) *In the Image of Cosmo Order and Symbolism in Traditional Islamic Architecture*. part 1, p. 5.

▪ Fountain and Architectural Typology

Much has been written on the typology of Islamic architecture from an essentially Western viewpoint. Contemporary approaches attempt to establish a connection between Islamic architecture with the modern architectural theories of functionalism and formalism. The most common approach of which is the one that claims that there is unquestionable functional polarity in the sacred architecture. While the presence of symbolic forms is more conspicuous in buildings that serve religious purposes, buildings that serve secular purposes are almost devoid of such forms.

Dysfunctional forms or objects are not of preference in the Islamic tradition, since every thing on the planet according to the Divine law has to serve its genuine purpose respectively. The symbolic qualities and functional values of these forms or objects, on the other hand, are the key components of the formalism. From a logical point of view the modern theory of functionalism is by no means applicable to traditional Islamic architecture. The fact is that function has hardly been the primary determinant of symbolic manifestation; for, it can not be always taken as the basis of building typology. Also, human activities or, in other words, the functionaries in traditional Islamic architecture can not be taken as a justification of the presence of its symbolism. This because the relationship between a form and its meaning is traditionally seen as being essential and not accidental or attributive as seen from the functional point of view. So, neither the symbolic qualities nor the functional values of the form are allowed to exist at the expense of each other.

Samer Akkach, in his article 'In the Image of the Cosmos Order and Symbolism in Traditional Islamic Architecture', part 1, has drawn three evidentiary points in which he gives a clear interpretation of the typology of Islamic architecture as opposed to the notion 'form follows function':

> First, the emphasis on the interior and the absence of form-function relationship undermine contemporary approaches which attempt to explain Islamic architecture with reference to the modem architectural theories of functionalism and formalism.

Second, the ubiquitous presence of certain built-forms throughout the Islamic world, such as the four-*iwan* courtyard which was seen as ... an absolute scheme, suggests the presence of an underlying and unifying spatial order of Islamic architecture.

Third, the strong emphasis on these built forms, which do not seem to relate to specific functions, directs the attention towards their meanings and symbolic significance.[4]

The conclusion that must be drawn from this interpretation of Islamic architecture is that there is no starting point, from which a form was initiated, which can be marked in the sphere of symbolism, functionalism or formalism. Although these spheres are the reading tools of the typology of architecture as well as being genuinely its design outlines, any judgement of a form cannot be based on an individual sphere without taking in account the integrity of the others.

Thus, we may take the fountain as an obvious example of this notion in which these three spheres, symbolism, functionalism and formalism have performed a harmonious relationship with each other. The integral relationships of these spheres make it impossible to define from which one the creation of the fountain was started. The medieval Persian mystic Awhadi Kirmani depicts the relationship between the form and its associated function and symbol in a beautiful poetic words, he writes:

"I gaze upon form with my physical eye
because there is in form the trace of the Spirit.
This is the world of the form and we live in forms;
the spirit cannot be seen save by means of form"[5].

[4] Samer Akkach (1995) *In the Image of Cosmo Order and Symbolism in Traditional Islamic Architecture*. part 1, p. 6.

[5] Quoted in *Islamic Art and Spirituality*. by Sayyed Hossien Nasr (1987) p. 165.

However, the philosophy that stands behind the creation of the fountain, however, had a different perspective and role in the architectural context of Roman and Greek civilisations. J. Carr explains that the Greek fountain is, in fact, "a practical tool", which only exists as a subordinate to an architectural setting. He adds that, as far as Hellenistic civilisation is concerned, fountains were in existence and they may have been concerned with "spectacle or appearance for its own sake", despite this there is no positive record of any sort of waterworks. On the other hand, Roman fountains were greatly influenced by the Greek, J. Carr explains, the way in which Greek architecture was regarded as a source book for much of Roman design. Roman fountains in the actual sense were exposed to the mercy of the political and personal needs of the patrons, although they were to have served an "aesthetic and a life-giving" functions. Nevertheless, the vulnerability of fountains to the "egoism" of politics was very great.[6]

This is not the case in Islam, as we have seen. The fountain in Islamic culture was totally integrated into the structure of daily life. It was not restricted to liturgical functions or to political use by kings and princes. The fountain, in fact, was the most present element within the fabric of architecture in the courtyard of religious and secular buildings, such as mosques, theological colleges, hospitals, palaces, and houses. Its design articulates a distinct dialect in the way in which the verb and subject were derived from the vocabulary of the natural and the cultural spheres. A. Spirn writes: "Design that resonates with the natural and cultural rhythms of a place, that echoes, amplifies, clarifies, or extends them, contribute to the sense of rootedness in space and time".[7]

The integrity of these rhythmic vocabularies created what we may call an "Architectural Theatre". On the stage of this theatre the elements of nature and the tools of culture were rehearsing to conduct a successful poetic play.

[6] Jason Carr (1993) *Patron, Ego and the Fountain in Rome.*
[7] Anne W. Sprin (1998) *The Poetic of City and Nature: Towards a new Aesthetics for Urban Design.* 110.

Poetics of Water-Architecture

The people of the great Greek civilisation had an aristocratic appreciation of architecture. This is reflected in the original Greek word "Architecture", which means "Frozen Music".

In Islam, however, the perception of the artistic and the poetics qualities in architecture emerge from the ideas and interpretations that are derived from the Arabic term *'Imara*, architecture, which in its linguistic definition means to inhabit the earth or the place. The implying ideas of this term *'Imara* as applied, in particular, to the sacred places are: (1) to build or serve, (2) to maintain in fitting dignity, (3) to visit for purposes of devotion and (4) to fill with light, life and activity.

These interpretations are reflected in a poetic expression as Jo Tonna depicts his own view on the poetic of Islamic architecture, in which he extracted a double sense as the very characteristic of its 'Poetics'; he writes that Islamic architecture:

> "As a system of forms and compositional rules comparable to those, which are used to spin words into poetry or sounds into music, and the poetic utterance or tragic discourse to which the form so composed are addressed. The forms, techniques, and materials that were drawn into this system were initially mined from the subject cultures but ultimately fused into an authentic expression of Muslim world vision"[8]. (Tonna 1990, p. 182)

These poetics, in a sense, are the other face of the "Islamic art of living", which is defined by an inner and outer dimensions that draw the outline of its philosophy. The inner dimension is manifested in the archetypical rules of behaviour derived from the religious tradition, whereas the outer dimension is realised by the man-made physical environment responding to his ideal pattern of life. The expression of these dimensions were the consistent endeavours of Muslims to create an environment in which values and qualities are manifested, at the same time satisfying the specific

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[8] Jo Tonna (1990) *The Poetic of Arabic-Islamic Architecture*. p. 182.

requirements of the corresponding way of life in the structure of a city, house, garden, as well as a courtyard. These structures in their turn were a dynamic mechanism in inducing and supporting the corresponding type of human behaviour.

Over time, urban forms always introduce a dialogue between nature's purpose and human purpose, where a courtyard is a clear example of representation for such a dialogue. Ultimately the courtyard in Islamic architecture was the interpretation that makes a synthesis of house, water, and garden. For every attempt was made to enhance the sense of being part of the garden without actually strolling in it. This highlights the notion in Islamic agronomy that lays stress upon the right proportion of a garden with its water-features within the courtyard, which must not be so large as to become a colossal eyesore; but that extra care should be taken in order to produce maximum delight in one view.

The courtyard and the rooms exposed to it, on the other hand, form the concept of defendable architecture. It provides a privacy and protected space that symbolises the inner life of the individual: light and air are the most practical functions it offers to inhabitants. It is a symbolic reflection of paradise where potted aromatic or flowering plants, fountain, shade, and seasonal bushes make up the simplest courtyard. Jonas Lehrman defines the root of word paradise, he writes:

> "The English word 'paradise' is derived from *patiridaeza* meaning an 'enclosure' or 'park' in old Avestan, a language that predated Persian. The Greek word *paradeisos* was adapted from the Persian, and came eventually to refer not only to the sublimity of the Persian garden but to the supreme bliss of Eden or the reward of the faithful as promised in the Koran. This Paradise was conceived as the ideal garden, and was portrayed as a state of blessedness"[9].

The court of the lions in the Alhambra palace is a distinct example of an Islamic concept of a courtyard and garden. It has been regarded as a monument that

[9] Jonas Lehrman (1980) *Earthly Paradise: Garden and Courtyard in Islam.* p. *31*

summarises several centuries of artistic development in the architecture of Islam. It has always been praised for the balanced composition of buildings, vegetation, and water. The use of a sophisticated system of proportion in its design shows no confusing beauty with size and scale. Y. Tabbaa writes:

> "The aesthetic qualities of the medieval Islamic garden was to no small degree based on poetry. This was not accidental. Garden poetry had already developed in the ninth-century courts of Sammara into a major poetic form, *rawdiyyat*, and spread from there to Sicily and Spain where it reached its peak of accomplishment. ... More than anything, however, they dwelt on water: running freely in a meadow, generously overflowing a pound, rising in a jet like a rod of rock crystal, or flowing in a channel like melted silver. The poetical inscription around the basin of the fountain of the Lions at the Alhambra palace is quite typical in this regard:
>
> Silver melting which flows between jewels, one
> Like the other in beauty, white in purity
> A running stream evokes the illusion of a solid substance
> For the eyes, so that we wonder which one is fluid
> Don't you see that it is the water which is running over the rim
> Of the fountain, whereas it is the monument which offers
> Long channels for the water" [10].

These poetic reflections represent the sense of balance that was introduced to all types of Islamic architecture. Whether in a courtyard of the sacred or the secular buildings there was no arbitrary separation between water and vegetation, between ornamental and productive and between pleasurable and pragmatic. This delicate balance and fine arrangement were reflected in the tendency to organise the living space in an inward orientation, which is a typical Islamic inclination. It was emphasised for its intimate

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[10] Yasser Tabbaa (1992) *The Medieval Islamic Garden: Typology and Hydraulics.* p. 325. This essay is the only study that dealt with the architectural significance and nature of the fountain from historical and archaeological accounts.

quality as inner habitations that turn their backs to the outside, and getting their view, sun, and light from the courtyard.

We may imagine how much relief developed as a man frees himself from the pressure of daily life while being granted a total privacy in his ideal image of the world. The enclosed space with the opening of the courtyard capture a personalised segment of the sky, with water, earth, vegetation, and sunlight representing the elements of nature, a complete cosmos is created within the restricted boundaries of human dwelling.

- **Fountain within Interactive Climate**

From the previous discussion we may deem that the principle of a central courtyard in Islamic architecture has created a micro-climate within which interactive responses occur between the fountain and building as well as between the fountain and the inhabitant. The fountain in this micro-climate can take better advantage of air-flow to increase a cooling effect, point of attraction, as well as mitigation of noise. By the means of a wind-capture, the cooling function acts as a concentrator of the prevailing wind that directs it over the fountain. Then cool air is created by the increased evaporation, which transports beyond the fountain into the interior of the courtyard or the building. The potential of a fountain to mitigate noise, on the other hand, is another feature by means of the sound of splashing, flowing or moving water can mask bothersome noises. Although the mitigation of noise is a practical application of a fountain, the desired result is to create a more pleasant environment and thus serves an aesthetic purpose.

Furthermore, the presence of a water-feature in an architectural form reflects many symbols and qualities besides its functional role. Some of these functions we already know, for instance that the fountain has served as an environmental mitigator and as a natural tranquilliser, yet the history has documented a rather interesting function as a safety element within the architectural environment. Al-Maqrizi[11] in his book *al-Khutat* reports about his observation of one of the palaces in Cairo, Egypt, he writes : "There is a fountain in every part of the palace full with water, which were set as a precaution of fire might occur during the night".

Interesting research concerning this subject was undertaken in the recent years. It was a survey to measure and understand public attitudes and opinions regarding the appreciation of decorative water-features, which was commissioned in 1992 by the Design Review Board of Phoenix, Arizona, U.S.A. Joe Gelt reports on the results of this survey.

- A majority of respondents expressed a negative opinion of fountains by opposing their out-door installation in new developments.
- The majority as well believed that the fountain should be located in a sheltered position for more enjoyment.
-

These responses demonstrate a discriminating attitude about fountains and what they represent. Joe drew a conclusion from this responses and put it in a number of points:

- Respondents are aware of the potential benefits of fountains.
- They believe fountains are to be viewed close up and are to be appreciated directly and personally.
- The public or civic value of fountains does not transfer to commercial applications.
- For many people commercial uses of fountains are unjustified.
- Finally, concern about excessive water use inhibits public appreciation of decorative fountains.

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[11] Taqi al-Din al-Maqrizi *Al-Khutat*. Vol. 1, p. 387. Al-Maqrizi is a $14^{th}/15^{th}$ centuries historian whose book '*Al-Khutat*' is an important travel accounts of the time, in which he recorded in detail his observations of life of people and their habitats in his time.

Here we may briefly conclude that water and its use for human purposes has great potential to forge emotional, functional and cognitive links between people and nature in the environment. This fascinating relationship between water and architectural environment is beautifully expressed by Stefano Bianca in his observation on the remarkable water-architecture in Fez which showed that man has made most judicious use of all elements offered to him by nature. These natural elements enabled man to produce a subtle example of balance between art and nature, simplicity and refinement, sensuality and contemplation. The fountain was that very distinct example which is regarded as a hallmark of Islamic works of art. Bianca states that "architecture...follows the rule of water, while in fountain, water is integrated into architecture"[12].

[12] Stefano Bianca (1985) Fes: City of Water, Garden and Fountain. p. 92.

Water-Features in Islamic Architecture

Although Thou art hidden...
in the heart and the soul,
Thou art manifest
to both the heart and the soul.

I see the whole Universe...
manifest by Thee,
Yes I see no sign of Thee...
in the world[1].

The history of Islamic architecture has documented three types of water-features; all present in both the secular and the religious buildings. Muslim architects always sought the noblest materials to construct water-features, i.e. fine marbles, stones. They never hesitated to use lavish decoration such as intricate mosaic, fine cut gems, and gold-leaf. In a pursuit of honouring the water the architect implemented several methods of techniques and designs. These designs were meant to stress the symbolic metaphors, the aesthetic qualities and the functional values of water-features. Therefore, the very heart of all buildings, the courtyards of mosques, schools, houses and palaces, were occupied by water-features. I will delineate the nature and the origin of each type of water-features in Islamic architecture and highlight its metaphorical meanings and functional concepts.

[1] By the thirteenth-century Persian mystic Farid al-Din Attar and quoted in 'Islamic Art and Spirituality by Sayyed Hussein Nasr 1987, p. 100.

1. *Sabil* (Drinking fountain)

The first water-feature is *Sabil* (drinking fountain). This term derived from the verb *Sabala*: to dedicate (thing) to charitable act or for God sake, (Thing) that's made permissible by setting a much-frequented road to it. The word *Sabil* in itself also means path or road.

Sabil is apparently an expansion of the custom of offering pilgrims water in pre-Islam times. Yet, in Islam it has taken wider approaches and appeared in numbers of distinctive formats. Muslim architects were inspired by the perceived image of a spring in paradise. This image occurs in many places in the Koran, by the inspiration of which the architects tried to create a metaphor in drinking fountains (*sabils*). They sought to erect, not just a public source of water, but a holy building proper for divine revelation, since water was perceived as a divine and not a temporal gift. This obviously defines the connection between Islamic doctrine and the drinking fountain (*sabil*) building.

The architectural setting for *Sabils* buildings varies from one Islamic State to another, although, the principles on which the *Sabil* is based are clearly found in every example throughout the Islamic world. The finest structure of these *Sabils* was executed in both religious and secular buildings under the Mamluks and the Ottomans in elaborate and sophisticated styles. A typical example of the *sabil* building is usually a square or rectangular space invariably built into the corner of the building where streets intersect adjacent to the main entrance (figures 131, 132, 133). However, *Sabil* can be found as independent building uniquely in Ottoman architecture. The exterior structure of the sabil architecture is pure and simple, by contrast the inner space is always colourful and charming in which inscription dominates most of the interior decoration. The façade usually has large windows beneath which single or some times a number of spigots or troughs are fed from an in-built reservoir.

Sabil is not merely a building set for commemorative purposes. It is considered as one of God's houses that it is a shelter by God, and He is the One who gives water, the symbol of creation to the thirsty. History tells us that during the Mamluks time *Sabils* often employed Koran reciters, whereas the Ottomans made the *sabil* a place of prayer (*musalla*). One of the *Sabil* employees, therefore, acted as *Imam* (the leader of prayers in the Mousque), although some *Sabils* were used as a Koranic school.

Drinking fountains were celebrated in other civilisations before the advent of Islam; but were differed in their significances and applications from culture to culture. A comparative survey of drinking fountain structures in the ancient civilisations informs us about its notions and at the same time rules out under any possible connections between ancient and Islamic drinking fountain, *sabil*.

S. Mostafa concludes that the Egyptians dug wells mainly for irrigation and drinking purposes; but neither excavated hieroglyphic inscriptions nor Egyptian papyri have mentioned any religious dictum about the charitable offering of water to the thirsty. The same case is noticed with the people of ancient Mesopotamia and Persia, despite the fact that they dug wells and built cisterns and channels for domestic supply. The Greeks, on the other hand, built public fountains as well as cisterns in public and private places, but again there is no evidence that their construction had any particular religious significance. The Romans indisputably had an extraordinarily well-developed water system; this includes aqueducts, fountains, and baths. It is very obvious that the Romans appreciated clear running water and used it to create decorative patterns on their monumental buildings, like those created to commemorate and honour local heroes. They were possibly the first to use water for symbolic purposes; nevertheless there no religious significance was apparent[2].

We can therefore, come to a conclusion that the construction of the *sabil*, the drinking fountain, in Islam fundamentally differs in concept and applications from its counter-parts in antiquity.

[2] Saleh L. Mostafa (1989) *The Cairene Sabil: Form and Meaning*. pp. 33, 34.

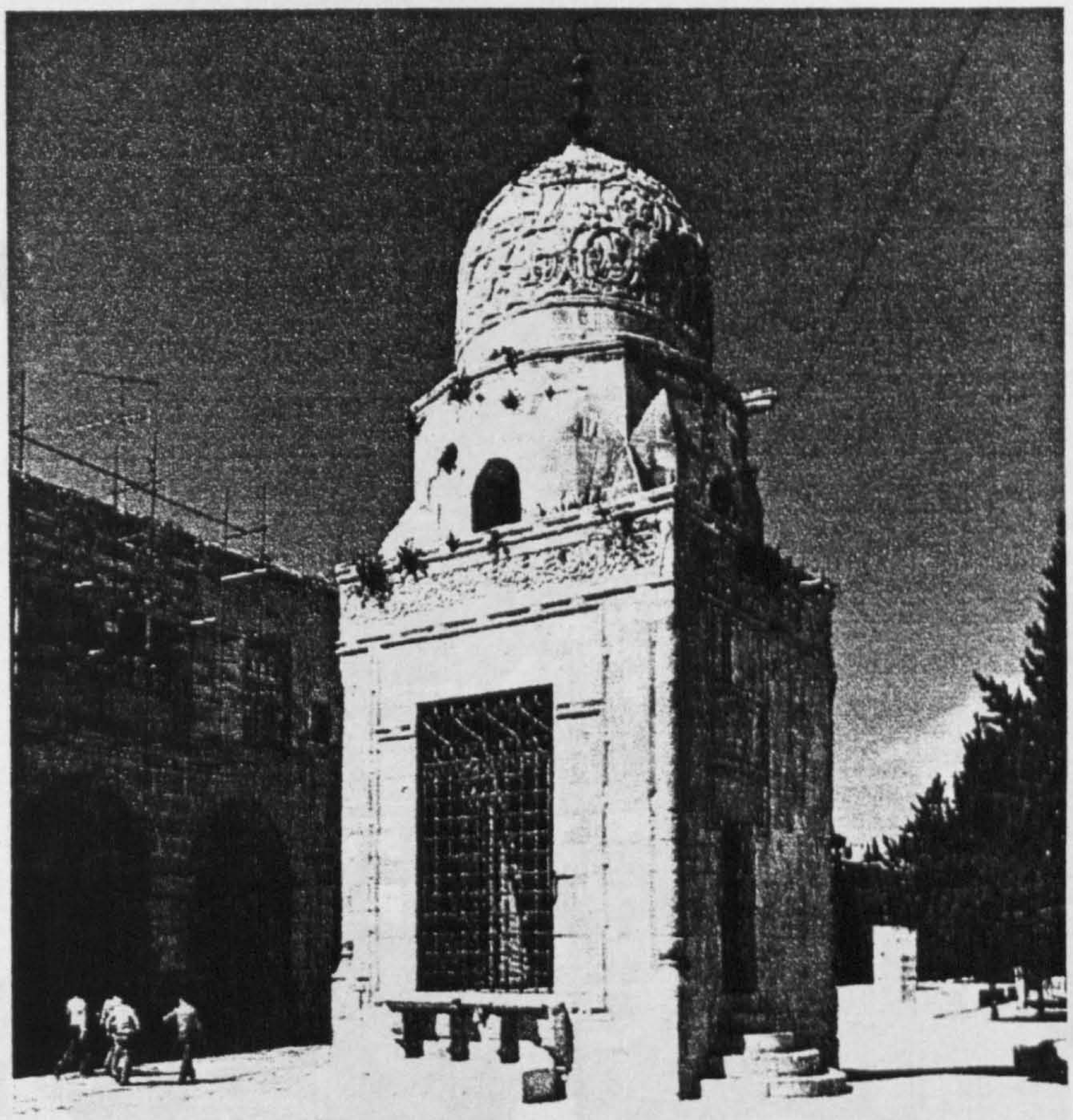

Figure (131). An example of a courtyard *Sabil* (drinking-fountain) erected in a religious sanctuary, called *Qa'itbay* fountain in Jerusalem on the *Haram al-Sharif*, 1482.

Figure (132). A example of a corner Sabil (drinking fountain) that is located at the intersection of streets on top of which an elementary school is erected, called *Sabil-kuttab* of *Qa'itabay* in Cairo, 1477.

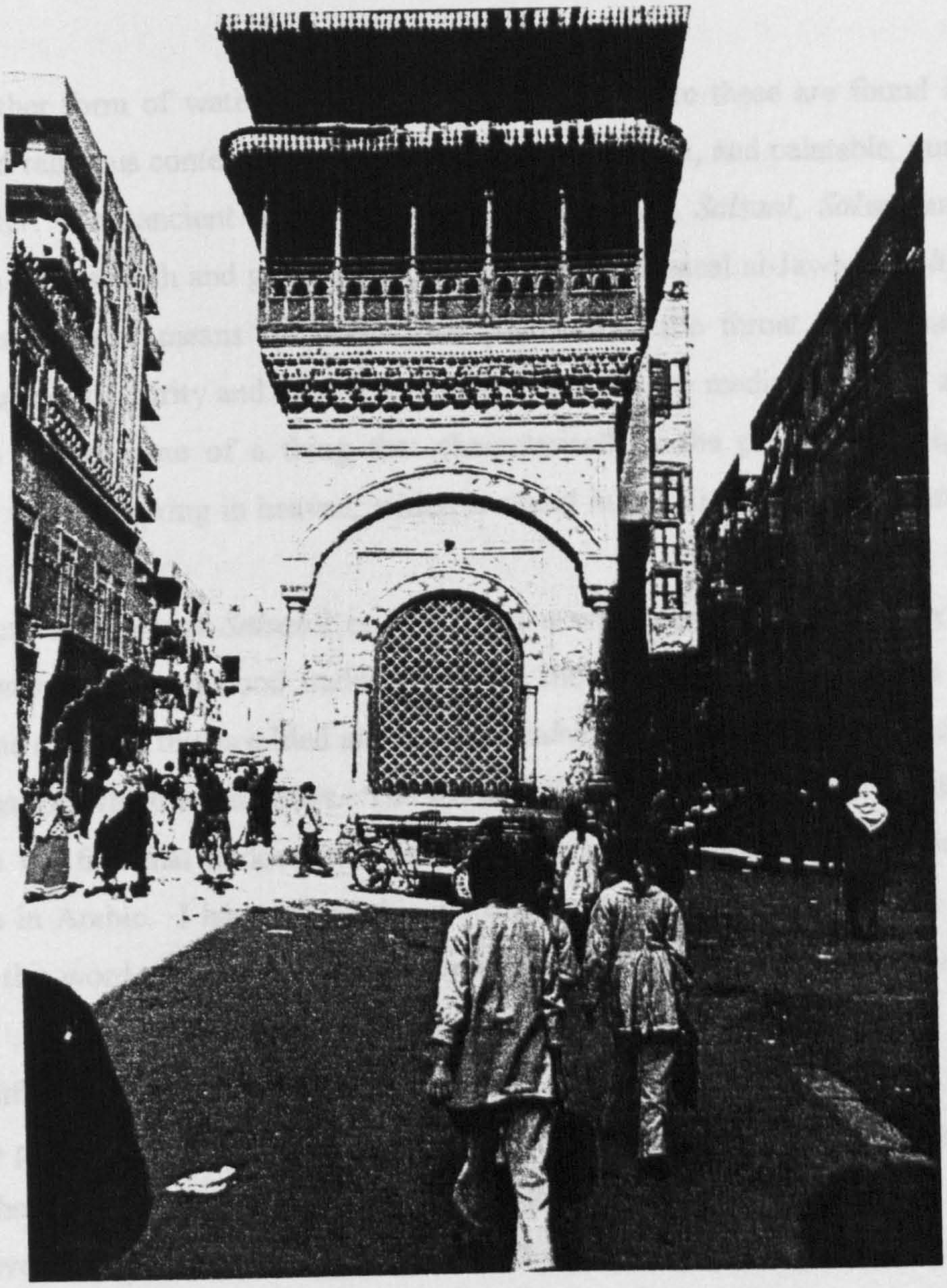

Figure (133). A free-standing (drinking-fountain) which is one of more than hundred such structures built in Cairo during the Ottoman dynasty. This *sabil-kuttab* has a water dispensary on the ground floor and is combined with a primary school for boys on the upper floor, 1744.

2. Salsabil

Salsabil is another form of water-feature in Islamic architecture these are found in both secular and religious context. The word *Salsabil* means light, and palatable, pure fresh, cool water. The ancient Arabs say: this drink is *Salis*, *Salsaal*, *Salsel*, and *Salsabil*, which means fresh and good taste. In al-Sihah of Ismaeal al-Jawhari *Salis*-water and *Salsaal*-water means the water that passes into the throat lightly and smoothly because of its purity and freshness. The *Salsabil* as the medieval writer, al-Zajaj, explains is the name of a thing that characterised by the property of high fluency, this is why the spring in heaven, which is stated in the Koran bears the name of its property, *Salsabil*.[3]

A typical example of *Salsabil* comprises of a water-spout surrounded by a colourful *Muqarnas* (grotto) hood under which an inclined carved marble slab is placed. In some example this is gilded and called *Shadriwaan* and it rests in the niche of the *Muqarnas* on which water flows. The word of *Shadriwaan* is in fact of Persian origin, despite the fact that it does not mean a waterfall or a cascade, even not a marble slab as in Arabic. I have traced this word and other similar ones in order to establish how this word comes to represent a water-feature in the Arabic architectural terminology. In the Persian-Arabic Dictionary the word *Shadurwan*-that is pronounced differently- means: the large royal-tent, which in the past used to be erected in the presence of the King; it also means the old and precious carpets and rugs[4]. The other similar word, '*Shadrawan*' means deceased or a respect word for the dead. However, the word '*Shadurwan*' in the Persian-English Dictionary means: a large veil, curtain or tapestry suspended before the gate of a royal palace; a richly figured carpet, a foundation a kind of moveable Turkoman house[5].

Tracing the meaning of the words 'Water-fall' and 'Cascade' in Persian language. Both the two words mean in Persian: '*Chadar*' which also means: a tent,

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[3] Quoted in *Al-ma'fi al-fikir al-Islami wa al-Adab al-Arabi*. By M. Abd al-Aziz Binabullah (1996) vol. 2, p. 192

[4] Abd al-Na'im (1982) M. Hassanaian *Qamows al-Farisyyia*.

[5] Persian-English Dictionary (none) p.722.

pavilion; a mantle scarf; a veil; a sheet; a table cloth. This word '*Chadar*' is used by the Mughal to name the lavish waterfall and cascade widely erected in the emperors palaces; figures (135, 136 and 137) show examples of this water-feature in the Mughal architecture. Therefore, we find in the Urdu-English Dictionary the word '*Chadar*' means: a sheet, a table cloth, a coverlet, a sheet of iron, a waterfall, a cascade, a veil. The conclusion I have come to that the word Shadriwaan in Arabic is comprised of two words. First, the Persian word '*Chadar*' which means a 'cascade', and the Arabic word 'iwan/iwaan' which means: pavilion or hall with arched openings, totally open on one side. Since the letter 'ch' has no an equivalent in Arabic alphabet, it was changed to the Arabic letter 'sh'; so the whole word became to be 'Shadr'. Then the Arabic word 'iwaan' was attached to it; the simple justification for this combination is that this water-feature always designed to be as a part of the architectural setting of a pavilion or a hall. Whether the cascade being erected in side the pavilion or outside it, the water flows through that pavilion down to the cascade. As far as Arabic is concerned it is safe to say that the word '*Shadriwaan*' means a pavilion-cascade.

The *Salsabil* word which names this superior water-feature is derived from the long journey and smooth flow of the water over the carved chevron pattern on the *Shadriwaan* and through the long channel into the pool. The action of water achieves an interplay between the sound of the trickling water and the irregular flash of the sunrays reflecting from the gilded or plain sculptured surface of the *Shadriwaan*. The water is then collected in a shallow pool from which along a thin channel (*qana*) water runs through the middle of the *iwan* where it is collected in a large pool in the middle of the courtyard, which often garnished by a central fountain or a number of fountains. Figure (134) shows the only medieval survived *Salsabil*, which represent the most typical Salsabil in Islamic architecture. The most elaborate examples of the *Salsabil* are found in the Mughal garden in the sub-continent, which are erected in indoor or outdoor architectural setting and characterised by their lavish scale. See figures (135, 136 and 137)

Despite the existence of the *Salsabil* in religious sanctuaries and secular buildings there were no liturgical functions attached to it. However, the existence of this water-feature in the secular and liturgical environments can be introduced in two possible interpretations. Firstly, it may reflect the meditative implications in the religious context. On the other hand, it may be associated with the palatial joy in secular context. However, neither meaning dominated the other, as their harmonious coexistence characterises the nature of Islamic art.

Thus the belief that the introduction of *Salsabil* in Islamic architecture was an attempt to celebrate the river as a natural phenomenon is totally rejected in Islam from a functional and aesthetic point of view. In fact, there is no certain reference in Islamic literature or affirmative evidence in any archaeological artefact that might reinforce such a claim. Furthermore, iconographic representation of the natural phenomenon has no trace in Islamic custom. This is also widely experienced in the interpretation of the gardens design in Islam. Many writers see the intersecting water-channels that linked to a fountain at their meeting point as a symbol of the four rivers in Eden; the fountain in the courtyard of lions in the Alhambra is a clear example of such arrangement. The fact is that the culture and tradition of pre-Islam civilisation significantly influenced the layout of the Islamic garden. Jonas Lehrman writes:

> "The book of Genesis recounts that a 'river' went out of Eden to water the garden; and from thence it was parted, and became four heads'. In Persian ceramics dating back approximately six thousand years, the world is depicted as divided into four sections by two axes that form a cross. At the focal point is a pool, or Spring of Life. This image may be related to the mandala of Buddhist iconography, and reflects a view of the universe and symbol of life that, possibly commencing in Iran, spread throughout the [land of] Islam. The symbol of four rivers, which branch out from a common source or centre in the direction of the four cardinal points, stands for fertility and timelessness.[6]

[6] Jonas Lehrman (1980) *Earthly Paradise: Garden and Courtyard in Islam.* p. 61.

Y. Tabbaa stresses that the notion to outdo Nature, illustrating a river in a *Salsabil,* is literally not so. The transformations of water are used allegorically to induce meditation on the inevitable and uncontrollable change of water. Perhaps more influentially to enhance the charming joy experienced by the spectator.[7]

In my investigation of the manuscript, in Chapter Four, I have come across a clear statement by the author of the manuscript *al-Riysala al-Qudsiya fi Amel al-Shadriwaan wal-Fisqiya* that reinforces the notion of the *Salsabil* in Islamic culture. The author of the manuscript described precisely the *Salsabil*, although he did not mention it by name, most probably his intention was to describe the *Shadriwaan* and the fountain individually. He writes: "*I wrote down a draft on constructing a fountain, **Fysqiya,** and a cascade, **Shadriwaan,** of perpetual motion type, which requires no external water source out of itself and its mechanical parts*"[8].

[7] Yasser Tabbaa (1987) *Towards an Interpertation of the Use of Water in Islamic Courtyards and Courtyard Gardens*. p. 215.
[8] See the first page of the translation of the manuscript *Al-Riysala al-Qudsiya*.

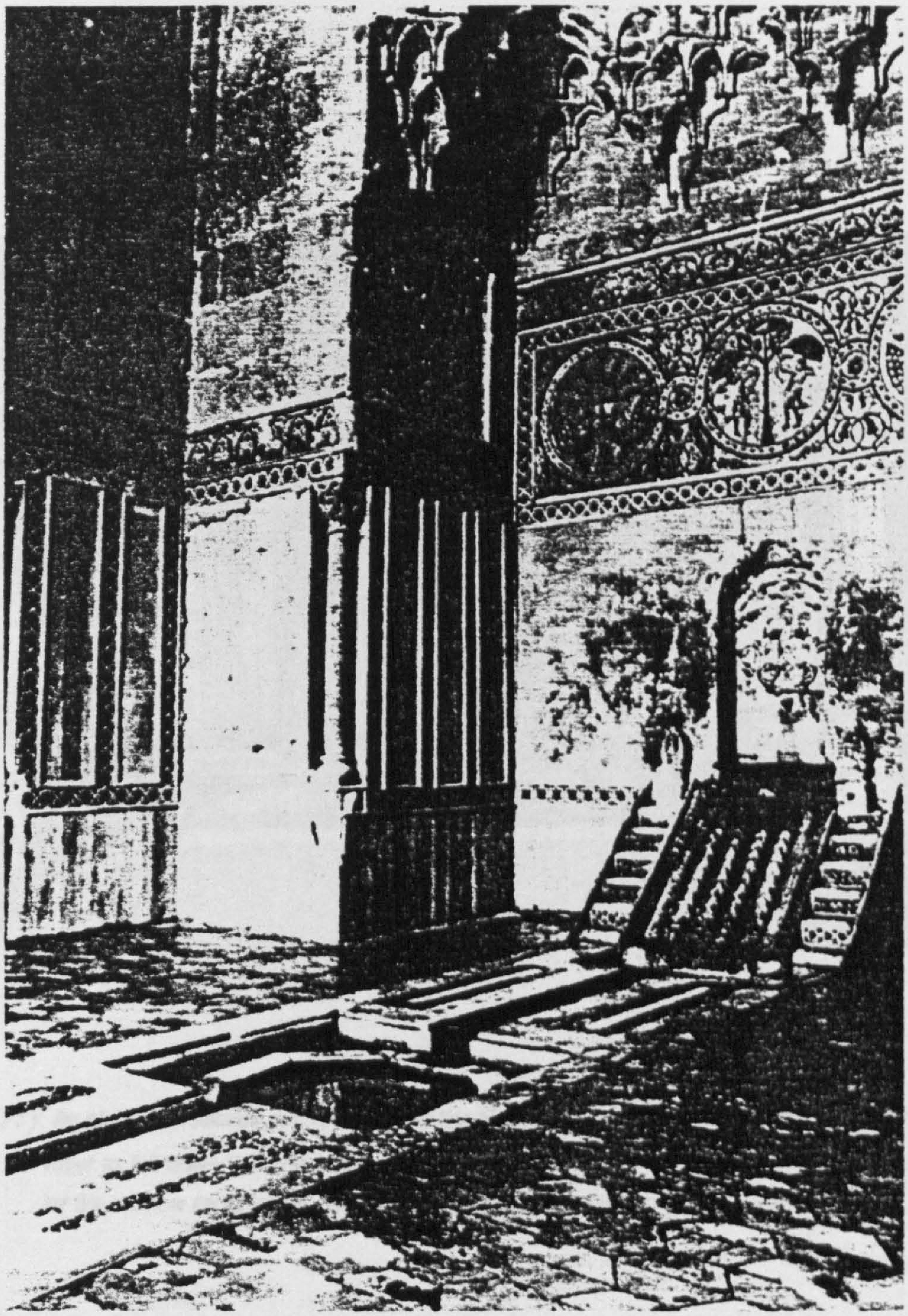

Figure (134). *Salsabil* in La Ziza palace at Palermo, Italy; it is the only medieval surviving one.

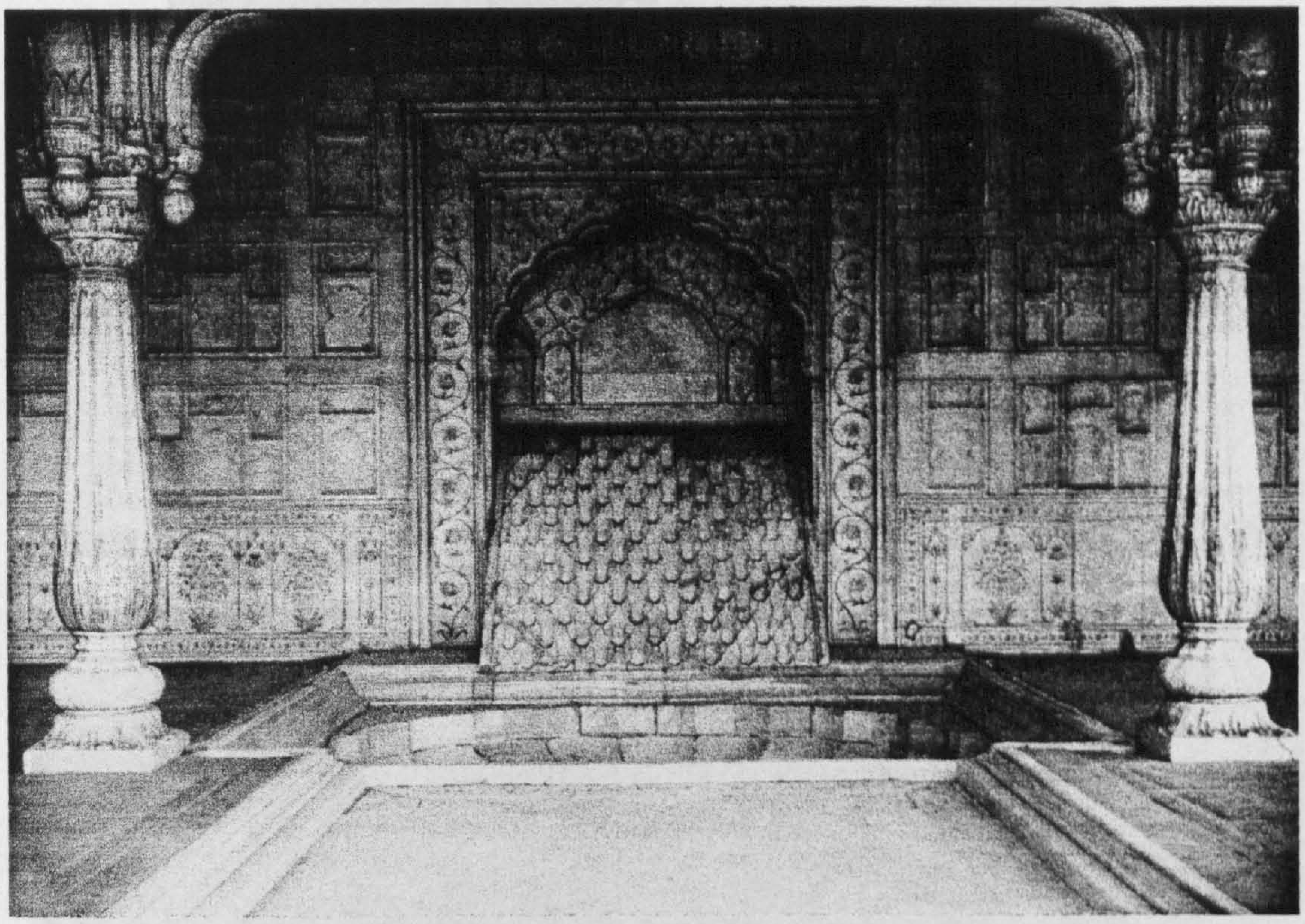

Figure (135): An elaborate Salsabil at the Interior of the Shah Bagh. Water is drawn from the Jumna River to fall down the *Shadriwaan* into the basin at its foot. The water then continued by the shallow canal to the Emperor's apartments, from which it fed the gardens, India.

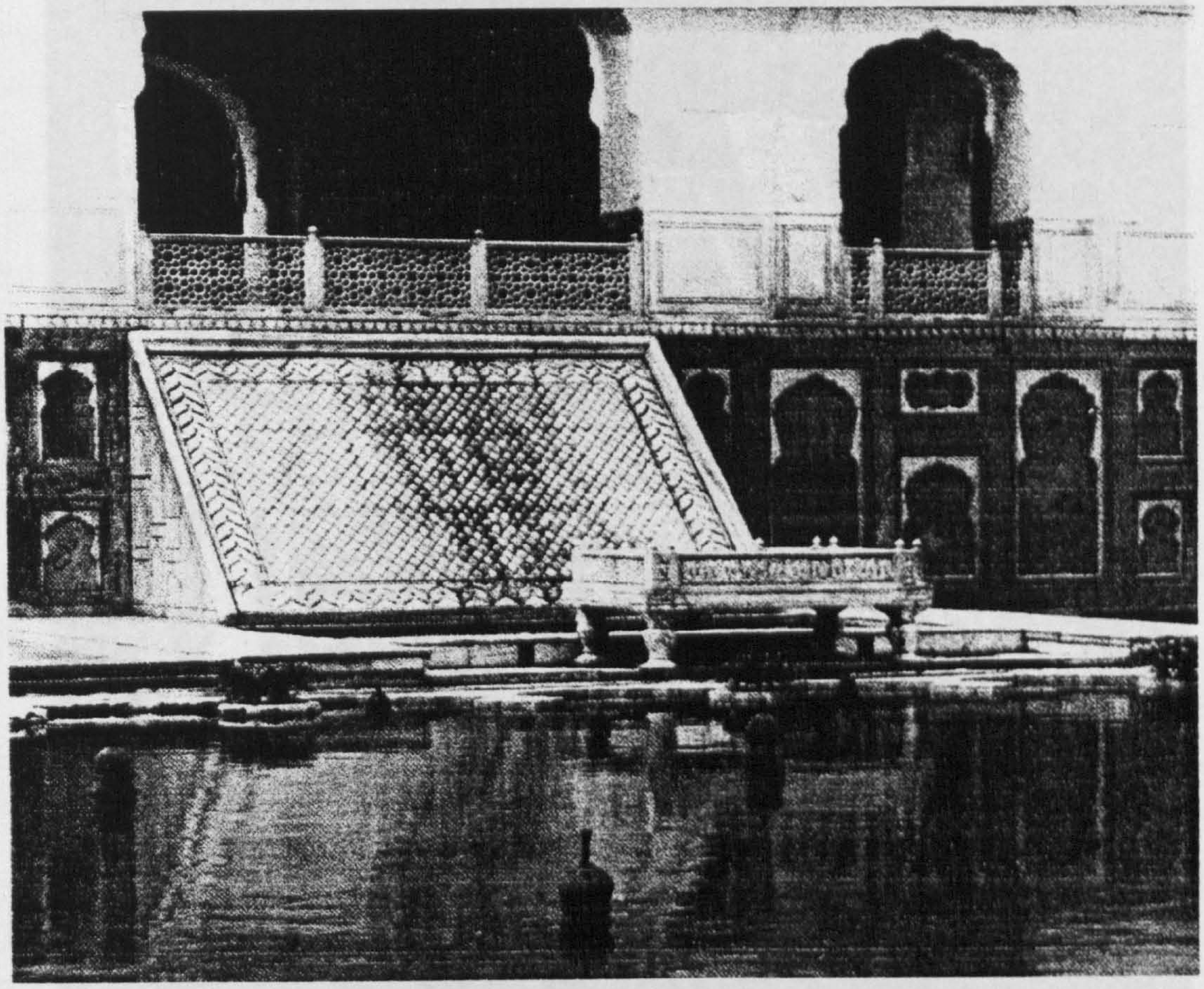

Figure (136): This is a lavish courtyard *Salsabil* in front of which the Mughal Emperor seated on his form once enjoyed the cooled air and the sound of the water as it flowed through the pavilion down the *Shadriwaan* across a shallow pool and under the Emperor's seating platform into the central reservoir, India.

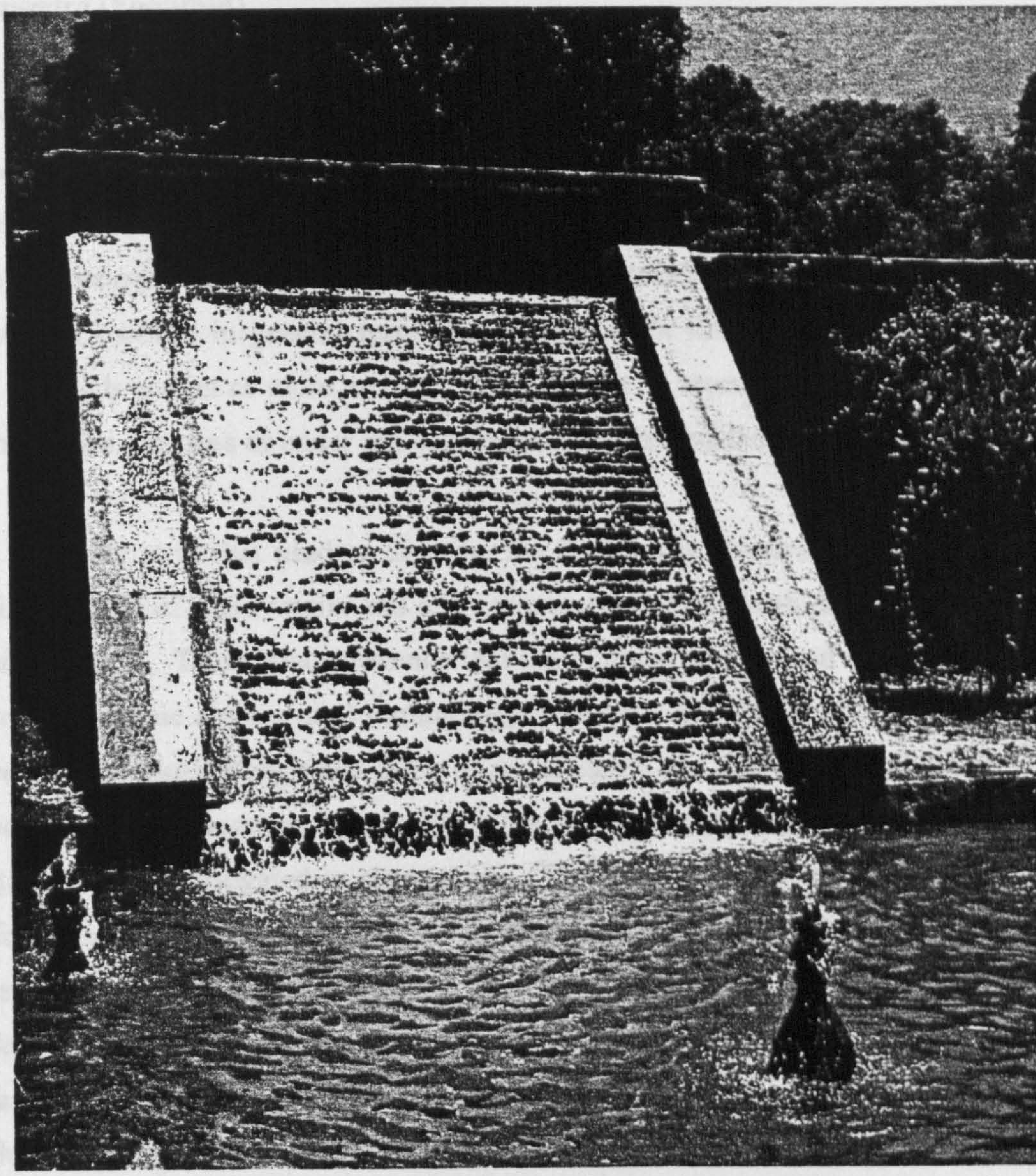

Figure (137): An outdoor *Salsabil* at Nishat Bagh, Kashmir, in which the carved *Shadriwaan* lead the water from beneath a seating platform to a pool containing fountains, India.

3. Fawaara (Fountain)

The word *Fawara* is derived from the verb *Fara*: to gush; water gushed from the ground and flowed. *Fawara* in its technical meaning is the fountain-jet which always centred in the middle of a pool, *Birkaa*, or a basin, *Hawod*. The fountain could have a single fountain-jet, *fawara*, or a number of fountain-jets, *Fawaraat* (plural of *Fawara*). However, in general term *Fawara* means "a fountain that consists of a basin in which one jet or more are set. This fountain is erected in the courtyards of the houses and mosques or under the domed hall of paths and the palace rooms"[9].

Another term that used to describe the fountain is *Fysqiya*. This particular term is primarily of Latin origin, and it is commonly used in North African countries, especially Egypt. There is no reference that may inform us how and when this term interred the Islamic architectural terminology. Also we find no trace of this term in the work of the Muslim engineers Banu Musa, al-Jazari and Taqi al-Din. Howener, it is reported in the manuscript, The Qudsiya Treatise on Constructing A Cascade and a Fountain, I have investigated in chapter one. The manuscript differentiates between the fountain-basin, *Fysqiya*, and the fountain-jets, *Fawaraat*, although *Fysqiya* represents the fountain in general terms. In order to find the common term in Latin, I looked up for similar and relevant word in Latin and English dictionaries; the most relevant and close term to the Arabic version is the term, *Piscina*, which means: "(1) A fishpond; a pond, basin, or a pool; among the ancient Romans, a public or private pond for bathing or swimming. (2) A perforated stone basin for carrying away, the water used in rinsing the chalice and the hands of the priest; generally placed in a niche on the south side of the altar, though sometimes projecting from the face of the wall or supported on a short column"[10].

The fountain primarily, is the most distinct and common water-feature in Islamic architecture; it was introduced equally to both domestic and sacred buildings.

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[9] Abd al-Rahiam Galib (1988) *Mawoso't al-'imaraa al-Islamiyya*. p. 267.
[10] The Oxford English Dictionary 1989. Vol. XI, p. 903.

Muslims first copied the Persian fountain as early as the eight-century, before it was transformed into Islamic architecture. The introduction of this new water-feature into Islamic architecture was enhanced by cultural and religious symbols. Since running water is the main element of ritual ablution and a symbol of paradise it is clear that special attention was given to the fountain in creating architectural, spiritual and environmental symbolic feature within the religious and secular context.

The distinct design of the Islamic fountain appears in two typical forms. A sculptured marble basin with a column base raised above the ground, in the middle of which a single jet sends water straight up in the air to fall back into the basin. The other form is a simple round, square, or octagonal pool, in some examples a floor basin. The inner walls of the pool have intricate ornamental patterns composed of finely cut small marble panels or thousands of individually shaped element cut from coloured glazed ceramic tiles of 3-4 typical colours covering the inner and outer walls of the basin. The fountain-head is placed in the middle of pool or the basin with a single jet shooting the water upwards or with numerous jets located around the rim of the basin or the pool to create different patterns of emission (Figures 138, 139).

The first example of fountains in Islam was introduced in the first half of the eighth century. The eighth-century Umayyad palace of *Khirabat al-Mafjar* (now in Jordan) contained the early example of an ornamental fountain inside a domed pavilion. The introduction of Islamic fountain came through the creation of gardens in palatial buildings. This was a manifestation of the new culture of the Islamic state; wherein at least two ancient civilisations the Near East-Persia and Mesopotamia seem to have provided a prototype for Islamic garden.

The celebration of the fountain aesthetic within the context of secular and religious buildings took different directions in Islam through a process of transformation; we have already discussed this in previous chapter. This equally worked with the other aspect of the fountain, which is the celebration of technological achievement in water manipulation. The Greeks and the Romans celebrated their technological achievements of water manipulation in elaborate fountains and other water-features as a sign of power and glory of the state. This notion came down to Muslims who were basically the inheritors of Greco-Roman technology. Therefore, they used fountains as a representation of one of their greatest accomplishments in technology. Each civilisation, however, chose a distinct pattern to celebrate the pride and power in technology, which represents the culmination of architectural manifestations for a people whose aesthetic taste reached a high degree of sensibility. It also shows the remarkable technical achievement that made water manipulation workable in the gardens and courtyards for the first time.

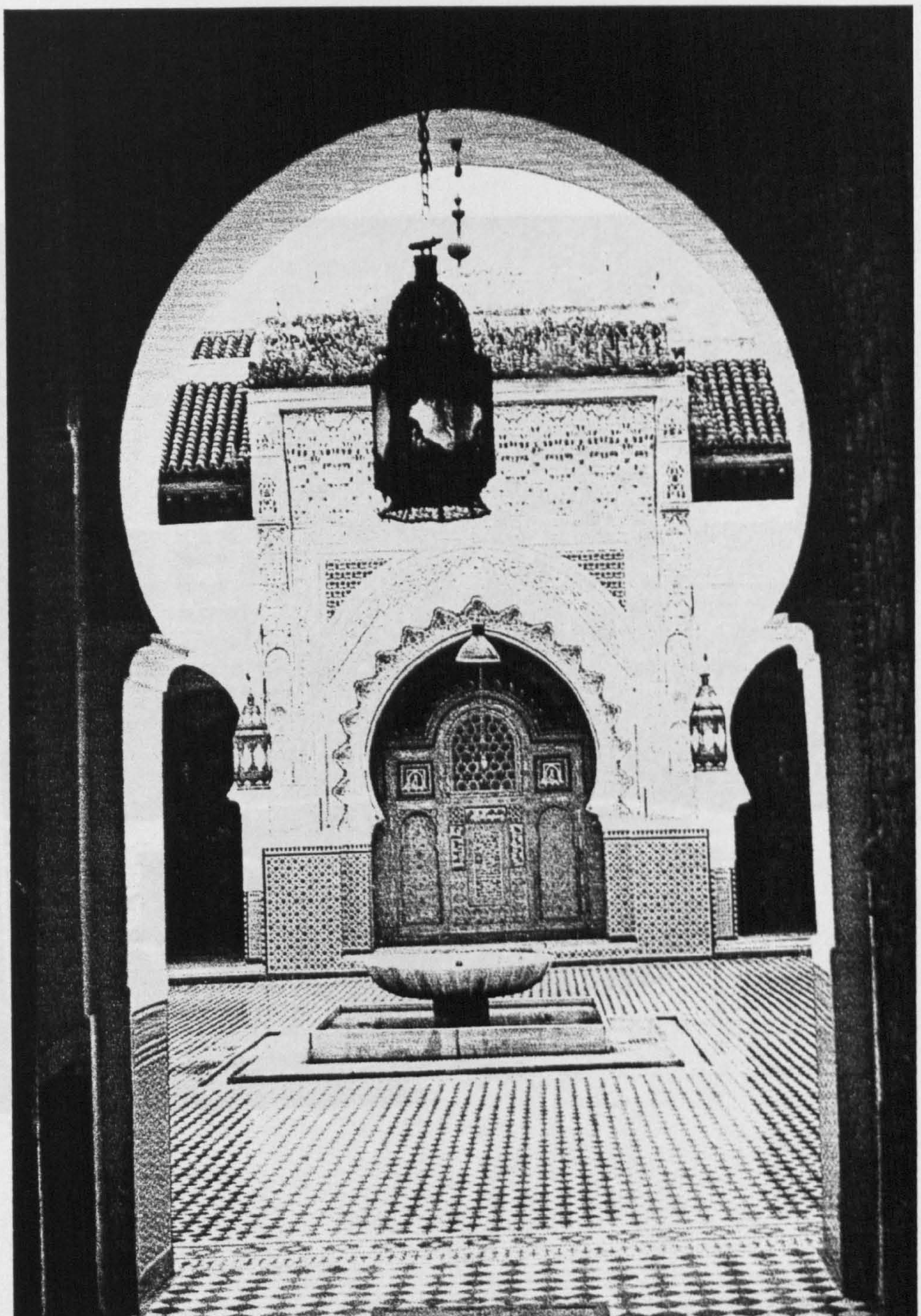

Figure (138). An example of raised pool fountain in a courtyard of a Moroccan palace, Morocco.

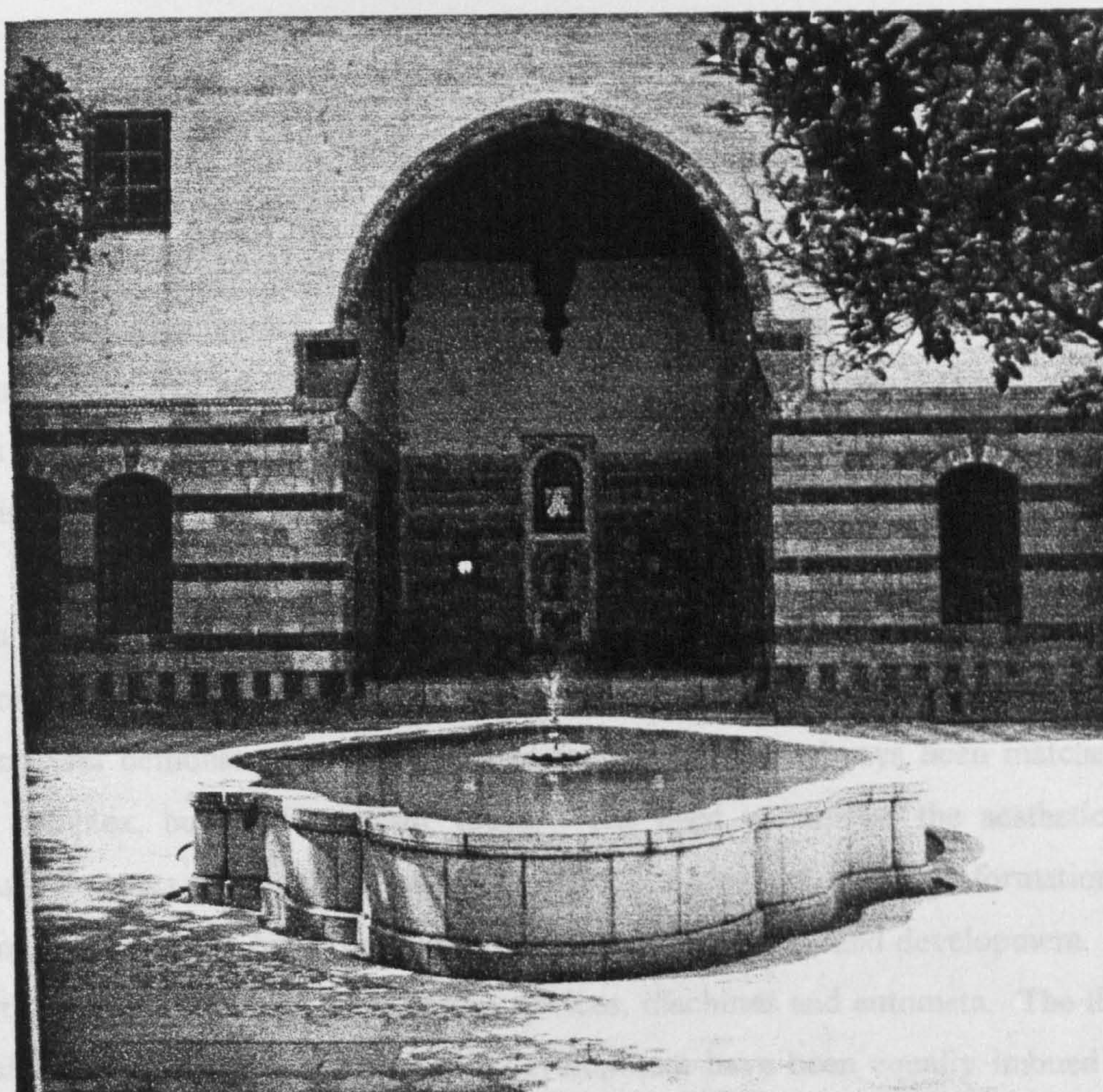

Figure (139) An example of a floor-basin fountain in the courtyard of *al-'adm's* house, Damascus, Syria

Engineering and Cultural Interpretation

All crafts are customs and colours of civilisation.
Customs become firmly rooted...
only through much repetition...
and long tradition.

Ibn Khaldoun*

All humans have culture, all therefore have technology. The cumulative heritage of experiences and techniques of a culture are the characteristics of its technology. This is clearly presented by the definition of 'Technique', in its original Greek meaning; that is "Focused Knowing" know nature- know how things really are- and then bring what is inherent in them into the open.

Tool making, on the other hand, is a basic element in the development of Homo sapiens. Survival dictated the need for artefacts associated with offence/defence, hunting and cultivation. However the history of technological development demonstrating that the need for survival has always been matched by more complex, but no less basic, urges. The need to express the aesthetic and spiritual elements of the human character and the tendency to pursue information and control in the abstract have often led technological invention, and development. This is particularly true of semi-autonomous devices, machines and automata. The theory and philosophy that accompanied this development have been equally imbued with mankinds inherent spirituality and aesthetic sense.

Historians customarily suggest that the making of automata primarily evolved from the strong innate desire to imitate and control the surrounding world. Derek Price in his article 'Automata and the Origins of Mechanistic Philosophy' describes the story between Man and his environment as the way in which through the graphic and plastic arts Man begins to simulate the world about him with a deep-rooted urge. In primitive religion the very interesting, naturalistic rock paintings of prehistoric

* A prominent 14th century sociologist and historian.

caves, the ancient grotesque figurines and other "idols", testify to the ancient origin of this urge. It is clear that man had taken the faltering steps toward elaborating pictorial representations with automation long before the Greeks. He adds another human characteristic as the making of automata was forged by the urge towards mechanistic explanation, and that much of our technology has evolved from automata, particularly the part embracing fine mechanism and scientific instrumentation.[1]

In his article Bedini, S. A. supports this notion on automata, by means of which Man attempted to simulate nature and domesticate natural forces. He writes that the technological advances of the space Age are the result of these attempts to imitate life by mechanical means, by which Man subsequently articulated the principles necessary to produce such complex mechanisms[2].

In fact this notion is in a sense pragmatic and insufficient to give a comprehensive interpretation of the relationship between Man and the quest for automata. Murphy, S. remarks upon the argument of Derek Price that interpreted the machines from themselves and from the existence of treatises on automata and mechanics conducted by enlightened scholars. He (Murphy) stresses the neglect of other two major sides, the ultimate philosophical side of science and the consideration of other unphilosophical motivations for constructing automata.[3]

Before discussing the influences involved in machine making, those that cement the human interaction and experience with the process of its design, we ought to define automata. When we speak about automata historically from the time of Greeks and onwards, it is connected with fine technology, although there was no such separation between what is utilitarian and what is fine technology. The term fine technology by definition means those types of machines or scientific instruments that bear aesthetic and precision quality and were fashionably designed to give pleasure in the courts of ruling elite and hierarchy community, or for timekeeping or for the scientific use, primarily in astronomy. Fine technology is thus distinguished from

[1] Price, Derek. J. (1964) *Automata and the Origins of Mechanism and Mechanistic Philosophy*. p. 10.
[2] Bedini, Silvio. A. (1964) *The Role of Automata in the History of Technology*. p. 24.
[3] Murphy, S. (1995) *Heron of Alexandria's On Automaton-Making*. p.5.

strictly utilitarian technology which is concerned with domestic machines such as water-raising devices, mills, and textile machinery.

Be they fine or utilitarian technology our basic concern is their out-comes, in other words, the artefact, (artificial object) that man produced. To bring satisfaction to our persistent needs we create new artefacts. We exist in the natural physical environment and function in a socio-cultural environment; the artefacts we produce correspond with our conception of the environments we live and function in. These artefacts create another form of environment, in a sense it is an artificial one a techno-physical environment. In the process of designing an artefact the natural and socio-cultural environments represent one part of the process. The opposite interacting part is the techno-physical environment. Each part influences and is influenced by the other, although the two environments in the first part interact with each other.

The socio-cultural environment and natural environment constitutes our objectives and values and forms our physical and non-physical needs, for example the need for aesthetics, which bears its own philosophy. Then our intent to create artefacts is to perform certain functions, whether they are utilitarian or aesthetic.

An artefact or designed object only comes into existence to satisfy human purposes. M. A. Rosenman and J. S. Greo give a clear interpretation of the design process by means of which Man comes to produce machines or an artificial object in general. They write:

> "Design is a purposeful human activity in which cognitive processes are used to transform human needs and intent into an embodied object. Humans operate in a socio-cultural environment, whereas artefacts form part of an artificial or techno-physical environment, the two being integrated into a socio-technical environment. Design is about the transition of concepts from the socio-cultural environment to the description of technical objects"[4].

[4] Rosenman, M. A. & Greo, J. S. *Purpose and Function in Design: from the Socio-Cultural to the Techno-Physical*. p. 161.

We may infer that the interpretation of the philosophy of automata in relation to the nature is more associated with the meaning of the word 'automata' and all related relations rather than concentrating on the detailed meaning of the word. Therefore, the relationships between all environments within which mankind act as an active part. So all interactions that occur with the surrounding environments transform his ideologies and philosophies. Thus the philosophy of technology in general, as being the interest of this thesis, clearly appears in a distinctive formation in every civilisation; this of course due to the differences in the influences and interactions between all environments involved.

Philosophy of Science and Engineering in Islam

The civilisation of Islam formed a bridge that linked the ancient with the modern world. Muslim scientists and engineers had received the scientific heritage of their predecessors, where these inherited scientific works flourished and grew in the culture and environment of Islam, through a continuous process of invention, research and development. A millennium of work on sciences and technologies were later passed on, by various means, to the Western world in which the enlightenment era took place.

Here it seems to be necessary to introduce some historical accounts on the scientific transmission that took place during the early time of Islam. Historically, the transmission of the Greco-Hellenistic tradition to Islam was not a direct one; several centuries of Christian history lie between the golden age of Alexandria and the rise of Islam. Alexandria was the main source of Greco-Hellenistic heritage to Islam as it was transformed into a major intellectual centre of early Christianity, before declining through severe pressure, especially from Constantinople and Antioch. Finally, to bear witness to the death of its scientific glory, by the brutal hanging of Hypatia, the daughter of Heron and the tragic burning of its fabulous libraries. Luckily before this incident some scientific work had been saved and the main intellectual activity of Alexandria had been transmitted to Antioch which was one of the channels that linked the intellectual life of Antiquity to that of Islam. Later the centres of learning of the eastern churches were pushed further eastward to Edessa, Nisibis and finally to the Persian Empire itself.

As the Persian land came to be conquered by Muslims, the road was a paved to Muslim scientist to access many Persian sciences and ultimately some of Greek and Indian origin. The Sasanid intellectual centre at *Jundishapur* (in the Ahwas region, south-western Iran) was a cosmopolitan gathering place for Greek and Indian scientists. This Persian centre excelled in many fields particularly in medicine. It is regarded more than any other centre to have been the living link between Islamic science and the ancient world.

Indian science on the other hand had a visible effect upon Islamic science and became one of the notable elements that contributed to its birth. Numbers of Indian scholars made scientific journeys to Baghdad and other Islamic intellectual centres as Muslim rulers were invited them.

No traces of the official transmission of the Chinese scientific tradition are visible within Islamic sciences until the Mongol invasion, thirteenth-century. But there is no doubt that there was some kind of earlier contact. One of the most important transmissions of Chinese technological inventions to the Muslims was the technique of paper-making.

The fertility of the new civilisation, Islam, for the cultivation of knowledge and scientific seeds inherited from the neighbouring former and contemporary civilisations was the making of that fruitful land. However, the actual process of transmission of the sciences of ancient civilisations from such languages as Greek, Syriac, Sanskrit and Pahlavi into Arabic is regarded as one of the most remarkable instances of cultural transmission in human history.

Yet, it can be difficult to understand the Islamic sciences without brief reference to the principles of Islam. To understand also the environment and conditions that constituted in time and space by the creation of Islam, the life-giving force of a vast civilisation for the cultivation of knowledge and sciences.

As far as engineering is concerned it is considerably important for an understanding of Islamic science as well as technology is to have a bird's eye view over its philosophical values on science and technology compared to that of ancient and modern civilisations. This can be obtained by studying history of science, technology and art in Islam, for example, the interactive role of the mechanical devices appeared in number of elaborate engineering manuscripts within the natural, cultural, social, and technological environment.

The cultural environment Islam created was the ultimate force behind the rise of the Islamic sciences and their later development. It is inconceivable without the predominant presence of the Islamic revelation spirit. This revelation has transformed the conceptions, actions and surroundings of the men and civilisations responsible for the creation and cultivation of the sciences. S. H. Nasr interprets the relationship between culture and science:

> "The unifying perspective of Islam has never allowed various forms of knowledge to be cultivated independently of each other. There has, on the contrary, always been a hierarchy of knowledge, in which every form of knowledge from that of material substances to the highest metaphysics is organically interrelated, reflecting the structure of Reality itself"[5].

- **Realism of Science and the notion of Sacredness**

The classifications of sciences from the Islamic point of view is based on principles that differ from those of the Aristotelian archetype: similarities and proximity of sciences. No longer do we find the duality in classification "theoretical" and "practical" or the hierarchical arrangement, which regards the more abstract sciences to be more advanced. The classification of sciences in Islam was based on realism, which is the reality of sciences in their origins, development, their intergeneration, and their actual status and the epistemological awareness within the Islamic environment. This realism as the main characteristic of science classification appears clearly in the work of Tash Kubra Zadah. His book *Kitab Miftah al Sa'adah wa Misbah al Siyadah fi Mawdu'at al'Ulum*, which is considered to be the greatest Islamic encyclopaedic work on the classification of science. It is based on the arrangement of material things within existence. Those have been gathered from the actual cultural and intellectual activity of the Islamic environment, and is arranged in four ranks: writing, expression, minds, and essences, to which all sciences are bound. Those sciences related to the first three ranks are instrumental, while those related to the fourth are either revealed law or reason.

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[5] Nasr. S. Hossien (1976*) Islamic Science: an Illustrated History*. p. 4.

Realism also appears, as Abdulmajid al-Najar explains, in the fact that the existence of the subject matter (e.g., elements of matter, states of matter, and immaterial beings) of the sciences cited were not the bases on which they were arranged accordingly. The reality of the sciences in their origins, development, their intergeneration and their actual status in the epistemological awareness within the Islamic environment was rather the real governor of this arrangement. He adds that the realism also shows that these classifications of sciences are in harmony with the reality of Muslim intellectual needs. Furthermore, the pedagogical considerations has been the very base of this arrangement, which seeks to facilitate the pursuit of learning and education for Muslims in line with the higher aims of life as stated by the Islamic faith. Therefore, these classifications appear to draw close to serving as a complete educational system for the Muslim nation. And also being integrated to meeting its needs rather than to serving as a philosophical classification of general human knowledge.[6]

This realism is also about the relationship between the natural and technological environment, which has always been spirituality sapient. This is why the quest for knowledge has possessed a particular religious aura even among common people in a way that is rarely found to this extent in other traditions, which is consistent with a spiritual overview of the world. What is of basic interest in this context is that technology dealt with and utilised natural forces within the environment, making the maximum use of human skills and causing the minimum amount of disturbance within the natural environment. As Asgher Ali writes this sincerity commitment to divine guidance and rational faculty can raise man to the highest and noblest level. While he is subject to being pushed to the lowest depths by the act of selfishness, lack of belief and rejection of divine guidance. Also degradation to the piety of other creations of God can be a result of such selfishness. He may be carried away by his selfish motives, ruthlessly exploit nature and create ecological imbalances, which ultimately endanger life in the environment.[7]

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[6] Al- Najar, Abuulmajid (1996) *Classification of Sciences in Islamic Thought: Between imitation and Originality*. p. 78.
[7] Ali, asghar (1993) *Islam and the Environment*. p. 25.

Islam took care of the social environment and alienated whatever might disrespect nature and consequently affects man's life. Of course there is a direct-relationship between a change in the composition of the natural environment and the composition of the social environment. It is believed that Muslims did not make practical use of all they knew about scientific theories and applications. They sincerely felt the premonition of danger of technological development, which, governed by the use of metals and fire and elements alien to the natural environment. Therefore the ultimate results would be in the loss of that equilibrium with nature which is the heart of the Islamic perspective and whose destruction is such a hazard for man in present days.
It is evident that Islam created the civilisation that had the capability to make complicated machines, many examples of which were described in several treatises. It is believed that Muslims did not take advantage of all that was known to them. S. H. Nasr writes:

> "Islamic civilisation had the means to make complicated machines and apply them to the problems of the daily life of the Islamic community. But like the Chines who had gunpowder but never made guns, the Muslims never took that step which would mean the creation of a technology out of harmony with the natural environment. Their works on mechanics dealt with a variety of subjects all the way from agricultural and transportational devices which were actually used in everyday life to complicated clocks ... to other complicated gadgets and devices"[8].

The sacredness in Islamic science is presented in the traditions that pay considerable attention to the ethics of the environment and sciences. For example many verses in the Koran, the Holy book, and in the prophet tradition state the sense of obligation and liability that man must hold in order to respect of all God's creatures. Therefore the utilisation of scientific and technological means must accord with the whole surrounding respectively, the air we breathe, the earth we live on, the nature we exploit, and every thing regardless of its nature. Parvez Manzoor writes that within

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[8] Nasr. S. Hossien (1976) *Islamic Science: an Illustrated History*. p.150.

the Islamic perspective, the debasement of nature by man leads to his own debasement and amounts to a revolt against the Creator. This environmental ethic permeated the entire Muslim society, particularly in the early times of Islam. It can be seen from such products of Muslim technology of those centuries as irrigation schemes, the physical layout of classical Islamic cities like Fez, Damascus and Isfahan, and the arts and crafts of that age. In fact, respect for nature among the Muslims is deep; which is why the development of technology under Islam was deliberately stifled when technology becomes a threat to the natural environment[9].

This realism in defining and positioning sciences in Islamic culture impose very strongly the notion of the sacredness of all sciences, which is clearly manifested in awareness and consciousness of the Divine law within oneself and the surrounding environments.

[9] Manzoor, Parvez. (1984) *Environment and Values: the Islamic Perspective*. pp. 161, 162.

- **Definition of Mechanical Engineering in Islam**

In Arabic literature, two terms were used to describe the Science of Mechanical engineering. The most predominant is the term *Hiyal* or *Ilm al-Hiyal*, (Science of Engineering), the other is *Al-a'lat al-Rohaniyya*, (Spiritual Devices). Although, the term *Hiyal* in engineering terminology is translated as 'Ingenious Devices', 'Automata' or in a broader sense 'Mechanical Engineering', by contrast it has rather ambiguous linguistic meanings. The semantic description of the term *Ilm al-Hiyal* is the science of ruses and tricks. Sayyed H. Nasr suggested that this view of science has always been connected in the Muslim mind with the occult and magic sciences[10]. Whereas Y. Tabbaa has different interpretation in which he gives a justifiable example, he writes:

> "The mechanisms in al-Jazari (book) are probably closer to the idea of *aja'ib* or wondrous creations. In this respect, they are in keeping with other wondrous elements in the Islamic garden, including man-made trees, column fountains, animal fountains, and other artificial devices. In all these fountains wonder is produced by artfully concealing the source of water and its passage through the fountain"[11].

On the other extreme M. A. Dhman describes the term *Hiyal* that is a plural of the word *Hilaa*, which means the cleverness in manipulating things and generating the mind with ideas through which man can reach his objective.[12] Dhman, however, rejects the interpretation of *Hiyal* as ruses, tricks and etc.

In the dictionary *Al-Monjid* (edition 28) we come across another definition that bears the same meaning as in Dhman's definition. It defines *Hilaa* as the ability of arranging manifold jobs, or cleverness and high conceptualism.

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[10] Nasr. S. Hossien (1976) *Islamic Science: an Illustrated History*. p.145.
[11] Tabbaa, Yasser (1992) *The Medieval Islamic Garden: Typology and Hydraulics*.p. 324.
[12] Dahman, M. Ahmed (1985) *Ilm al-Sa'at Wa al-A'mel Biha*. p. 28.

On the other hand, the other term *Al-aalat al-Rohaniyya*, (Spiritual Devices) bears much closer meaning. The first word *Al-aalat* literally means: devices, as well as the second word which means: spiritual. In the encyclopædia *Mifta'h al-Sa'ada* the author writes that it was called the Science of Spiritual Devices for the satisfaction of man's soul that conveyed through the action of the extraordinary devices.[13] The fourteenth century scholar Abi Abdillah al-Anssari introduces another more specific interpretation of this term. He writes: "it is the science that provides the construction procedures of the devices that based on pneumatic mechanism, like drinking devices and others. The benefit of this devices is to captivate the soul by the portentousness of these devices"[14].

From these different interpretations we may conclude a definition that sums up all that are implies in the term the science of *Hiyal* or *Al-aalat al-Rohaniyya.* So the Science of mechanical engineering, *Hiyal,* is 'The science of a proficient design of devices that functionally practical and aesthetically captivating'.

We find a very clear interpretation of the definition in the work of Muslim engineers. For example, the third water-lifting machine by al-Jazari in which the viewer was amused by a model of cow which appeared to drive the machine when the total mechanism was disguised from sight, (this is fully explained in the following section). Also it was articulated in the manuscript, I have discovered, '*al-Riyssala al-Qudsiya fi Amel al-Shadriwaan wal Fisqiya*'. The author of this manuscript explained the pleasure that can be obtained in watching the movement of the machine he devised, which was partially concealed from sight. He writes: "*because it is this sort of things, which is a ravish to the eye and such a pleasure to watch*"[15].

[13] Zadah, Tash Kubra. *Kitab Miftah al Sa'adah wa Misbah al Siyadah fi Mawdu'at al'Ulum*. Vol. 1, p. 379.
[14] Al-Ansaari, Abi Abdillah M. (1994) *Irshad al-Qasid Ila Asna al-Maqasid.*
[15] See the translation of the Manuscript *Al-Riyslaa al-Qudsiya.* P. 47.

Tradition of Mechanical Engineering in Islam

The tradition of mechanical engineering came into being in Islam during the translation movement[16] of the ninth century, although it did start much earlier. Its glory is always attributed to the ninth century which is when the most prominent engineers lived. The transmission of the most ancient science and technology took place in that era where they were gone under an intensive study and investigation.

As far as the technology is concerned, the Muslims during the translation movement in the ninth century accessed the traditions of fine technology that began in the Hellenistic world in the third century BC. The most important works that have survived were those of Philo of Byzantium (c. 200 BC) and Hero of Alexandria (mid-AD 100)[17]. Both works the *Pneumatics* of Philo and *Mechanics* of Hero exist only in an Arabic version. Suffice to say that the Muslims were the people of the civilisation who preserved and maintained the tradition of antiquity. Muslim engineers, however, were very conscious of the importance of their own inventions and designs; therefore they took the development of the inherited technology seriously, even each one of them was aware of the genuineness of his work from his predecessors and contemporaries. D. Hill reports that in introducing a comparison of the various Greek and Arabic engineering treatises it "suffice to say that the Arabs, although they took the Greek works as their starting-point, were considerably more advanced"[18].

Some historians and scholars were critical of Islamic mechanical technology. This criticism was based on the idea that it served only the trivial purposes of recreation and joy.

[16] The translation movement is regarded as one of most influential scientific movement in the history of world civilisations which lasted for well over two centuries (8th-10th cen.) was initiated in Baghdad during the dynasty of the Abbasids (750-1258). Dimitri Gutas (1998) discusses this movement in his book '*Greek Thought, Arabic Culture: The Graeco-Arabic Translation Movement in Baghdad and early Abbasid Society* (2nd-4th/8th-10th centuries).

[17] Philo or Philon and Hero or Heron are the most influential Greco-Hellenistic engineers on Islamic engineering and technolgy, whose work on mechanics and pneumatic are only survived in Arabic.

[18] Hill, Donald R. (1996) *Arabic Fine Technology and its Influence on European mechanical Engineering.* p. 26.

It can not be completely accepted that such mechanisms were exclusively devoted to recreation and the decoration of palaces, although they were constructed to please the ruling elite as well as for the sake of demonstrating their technical complexity and engineering quality.

The denial of such criticism is already shown in engineering treatises in which Muslims engineers described their work in well known elaborate volumes and many scattered treatises, in which the overwhelming chapters were devoted to utilitarian technology. It can be suggested that such misjudgement rests on one simplified comparisons between present-day technological, research, space exploration, and art with a previous one. A. al-Hassan has given al-Jazari as an example to justify this misjudgement, he writes:

> "We may safely conclude, then, that the preoccupation of al-Jazari, as well as his predecessors and successors, with the description of elaborate and complicated machinery, did not preclude them exploiting this technological experience and knowledge to the benefit of their society. But the development of their society, and the historical period, was not commensurate with a scientific or industrial revolution such as the once that took place some centuries later. Hence comparison of an earlier age with subsequent ages is not objectively sound"[19].

Furthermore, it is of primary importance to indicate the relationship between the craftsmen on one hand and the people of knowledge on the other; and the contribution this made to the flourishing of the art of mechanical devices in Islam. In western civilisation there was a wide gap between the craftsmen and the scientists, authors, and academicians on the other. Not until modern times have western engineers have gained a distinctive identity, or indeed have enjoyed prestige. By contrast, this was not the case in the tradition of Islamic civilisation, where engineers from the

[19] Al-Jazari, Ibn Al-Razzaz *Al-Jami Bayn al'Ilm wa l-Amal al-nafi' fi Sina'at al-Hiyal* (A compendium on the Theory and Practice of the Mechanical Arts). p. 19.

beginning occupied a noticeable status. The Muslim engineer was at no time alien to the craftsman; in a number of cases he can be considered an artisan. An example of such work of art and engineering is appeared in even a utilising device. Al-Jazari third water-lifting machine (See figure 140) in which water from a nearby lake or river fills a tank on the bottom of which a drain that discharges a steady stream of water over a mechanism concealed in a lower basin. The water drives the wheel by impinging on its scoops. Then the motion is transferred through a the gearing system first horizontally then vertically to pot-garland that dips into the top tank and carries the water to the top channel that delivers it to the due place.

The intriguing aspect of this machine is since the mechanism is completely hidden from sight, all that viewers could see is the water-wheel, *saqiya*, which appears to be propelled by the wooden model of a cow. Hill annotates that "the machine was intended as a decorative lakeside attraction with an element of mystification about it"[20] Thus, beside the practical function of such machine is aesthetically pleasing and from a design point of view is innovative.

[20] Al-Hassan, Ahmad & Hill, Donald (1992) *Islamic Technology: an Illustrated History*. p. 44.

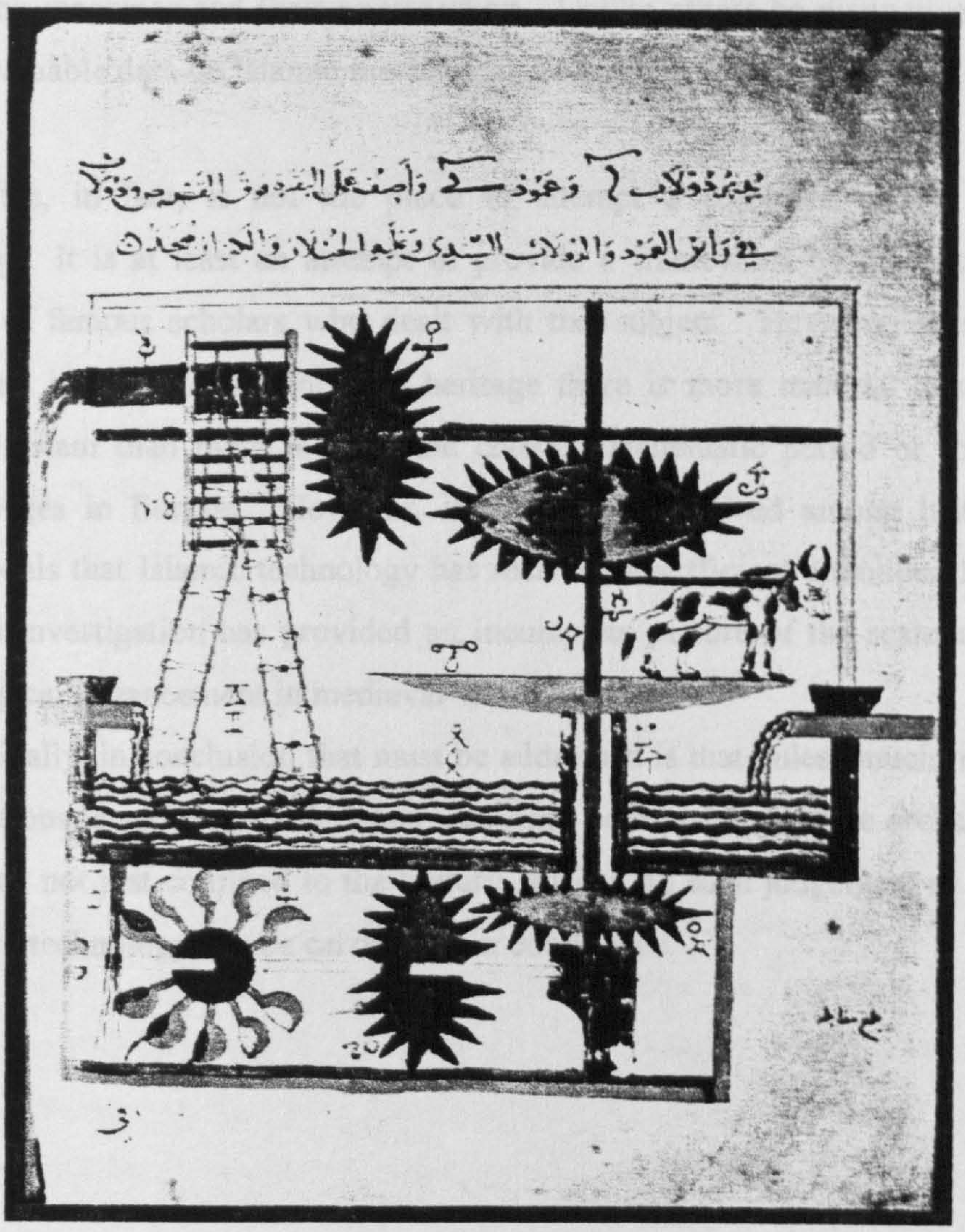

Figure (140) Al-Jazari third water-lifting machine.

Al-Jazari, however, represents the categorical example of engineers who combined 'theory and practice'. Many modern scholars regard his book 'The Book of Knowledge of Ingenious Mechanical devices' as the prime example of literature concerning machines and their construction. Unlike others he distinctively provides us with valuable data on Islamic mechanical technology of the time.

This, in fact, is not the place to attempt a complete review of Islamic technology. It is at least an attempt to provide a framework by presenting various writings of famous scholars who dealt with this subject. However, it is suffice to justify that in terms of engineering heritage there is more material available form medieval Islam than there is form the classical/Hellenistic period or for the early Middle Ages in Europe. However, it is strongly believed among historians and professionals that Islamic technology has received insufficient attention. This lack of historical investigation has provided an incomplete picture of the scale and level of technological advancement in medieval-Islam.

Finally, in conclusion that must be addressed is that unless much research and investigations is seriously undertaken, covering potential fields like archaeology and geography, not just confined to the literary studies; no such judgement or full review on Islamic technology can be carried out in confidence.

▪ Perpetual Motion in Islamic Engineering

As a natural endeavour to make use of elementary mechanics man became interested in the possibility of having machines work for him by themselves. The appeal of perpetual motion substantially revolves around the promise of a virtually free and limit-less source of power. In the history of the search for perpetual motion there is no trace of a single instance of established success. The fascination of perpetual motion has obsessed both inventors and the general public for centuries. It continues even in modern times, although it is without question impossible to produce. The scientific fact stresses that perpetual motion machines can not and will not work because they violate the laws of thermodynamics. However, in the recent times as ORD-Hume reports that the second law of thermodynamics; 'some energy is always lost in converting heat into work', has been proved that it may not be entirely true under all circumstances.[21]

This statement leads us into confusion, and wondering over the 'perpetual motion' and its meaning. Having said that, perpetual motion has long been, and remains an unsettled question to the modern times.

In The New Encyclopaedia Britanica defines perpetual motion as "the action of a device that, once set in motion, would continue in motion forever with no additional energy required to maintain it".[22] ORD-Hume writes that the ultimate definition of perpetual motion is that a machine, which will create energy.[23] A rather broader definition is introduced in the book 'Islamic Technology' by Hill and al-Hassan, they write that: "A perpetual-motion machine is simply one which does useful work without an external source of energy; or it can be a machine in which the output is greater than the input."[24]

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[21] ORD-Hume, Arthur (1977) *Perpetual Motion: the History of an Obsession*. p. 21.
[22] *The New Encyclopaedia Britanica* (1986) Vol. (9), pp. 302, 303.
[23] ORD-Hume, Arthur (1997) *Perpetual Motion: the History of an Obsession*. p. 31.
[24] Al-Hassan, Ahmad & Hill, Donald (1992) *Islamic Technology: an Illustrated History*. p. 71.

Yet, the definition of the perpetual motion implies controversial interpretations as some engineers and philosophers expressed their point of view over the quest for perpetual motion in the history of mankind. ORD-Hume summarises these two standpoints, that the philosophers believed that perpetuity is shown in man's abilities and skills to make something 'perpetual', be it motion or monument. The statues of commemorated people stand silently watching over squares in the cities could be considered if not truly perpetual motion, then a form of perpetual existence. The Egyptians pyramids for example represent a successful achievement of an admirable degree of perpetuity, since these were devised as the ideal shape for both durability and distinction.

On the opposite side, ORD-Hume adds that the engineers interpreted perpetual motion in a different perspective. The perpetual motion machine was seen as an engine- an ultimate mover- that benefits Man rather than just has something moving for the sake of motion. It had to overcome the laws of physics with sufficient margin to serve as an indisputable source of power for industrial applications.[25]

The question that needs to be asked is how Muslims viewed perpetual motion? In fact, the philosophical interpretation of perpetual motion in the work of Muslim philosophers has not been thoroughly investigated; in fact, there is no serious research to the present day where has been devoted to the study and analyses the perpetual motion machines in the Islamic engineering and philosophy. So it is improper and misleading to provide any definite interpretation over the Islamic view of perpetual motion whether it spiritually or scientifically motivated.

However, as far as the history of perpetual motion is concerned, in 891 the prominent geographer and historian al-Yaqubi reported for the first time devices that are driven by water without being driven by man or beast. T. Schioler in his book 'Roman and Islamic Water-lifting Wheels' drew a conclusion on this historical account that the attitude of Islamic scholarship regarded any type of machine not powered by man or beast as a perpetual motion.[26]

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[25] ORD-Hume, Arthur (1977) *Perpetual Motion: the History of an Obsession*. pp. 25, 26.
[26] Schioler, Thorkild (1973) *Roman and Islamic Water-lifting Wheels*. p. 61

An example of such machine that is not powered by man or beast, the intricate machinery of the fountain that is operated by a water source which is driven from a nearby river. The perpetuity of this fountain is maintained by this constant supply of the water, which is driven back into its source after being used to operate the fountain machinery.

Despite the fact that the definition introduced by Schioler cast a substantial importance in the philosophy of perpetual motion in Islam, more study and investigation are needed to acquire a coherent and complete picture of the nature and status of perpetual motion in Islamic thought.

- **Origin and Development of Perpetual Motion**

The concept of perpetual motion primarily is of Indian origin, which was probably rooted in the Hindu belief in the cyclical and self-renewing nature of all things. The earliest perpetual motion committed to paper was a manuscript on astronomy called *Siddhanta Ciromani* dated from the first half of the fifth century. This manuscript describes a wheel having on its outer edge a number of holes of equal size and at equal distances from one another, but arranged in a zig-zag in other words there were two rows of holes staggered around the tread of the wheel. These holes were to be half filled with mercury and then sealed over. It was claimed that if such a wheel were supported on an axis and the axis in its turn supported on a pair of props, the thing would rotate by itself once set in motion[27]. Not very much later, this concept was picked up in Islam, where it amplified the tradition of automata, inherited from the Hellenistic age. It is believed that around 1200 A.D as JR. Lynn White writes that Islam made the Indian concept of perpetual motion accessible to Europe, just as Hindu numerals and positional reckoning was in transmission at the time.[28]

[27] ORD-Hume, Arthur (1977) *Perpetual Motion: the History of an Obsession*. This book may be regarded as the most serious book on this subject, however the author dismissed Islamic civilisation through which the Indian idea of perpetual motion was transmitted to the West.
[28] White, Lynn (1978) Medieval Religion and Technology: Collected Essays. pp. 53, 54.

Perpetual motion was a natural development in Islamic technology, and represents the ultimate concern for the utilisation of power; in other words the minimisation of energy input. This philosophy was reflected in sixteen different machines, which were very briefly introduced by Hill and al-Hassan in their book, Islamic Technology: an illustrated history. They write:

> "The main concern of the unknown author was to minimise energy input, a concern which is reflected in the fact that six of these machines are of the perpetual motion type. But the whole sixteen machines embody one philosophy and one motivating spirit and must be taken together in any serious analysis".[29]

Although the definite failure of such machines is an ultimate fact, the primary significant they represent is the attitude of that period to certain engineering problems and provide important information about the designers who described them. We find, for example, in a manuscript an intelligible section, which reported by Schioler that deals with the technique of how to stop a perpetual motion machine, which is considerably huge. Of course the idea of introducing such technique by the author of the manuscript was intended to reinforce the reader's belief in the infallibility of these machines he devised. The conclusion Schioler has drawn from this descriptive technique is about the profession of the manuscript's author. He writes that since the author knows the danger of standing on the wrong side of the machine and how to secure it, the profession of the author appears to be either a crane builder or a turret clockmaker.[30]

Despite the fact that the failure of the perpetual motionists through the history of civilisations is evident, however, it advances the engineering knowledge and broadened the scientific understanding. The significance called 'technological spin-off', which is about reintroduction of an idea which thought to be impossible or a certain part of it into another domain of science and technology. In modern times it

[29] Al-Hassan, Ahmad & Hill, Donald (1992) *Islamic Technology: an Illustrated History*. p. 70.
[30] Schioler, Thorkild (1973) *Roman and Islamic Water-lifting Wheels*. p. 78.

already proven that some ideas applied in medical applications, as an example, have been originally extracted from science fictions. As far as perpetual motion is concerned, we find the design of the self-acting mill, which designed by Georg Andreas Bockler in 1686, the motive blades of which bear a strong resemblance to the modern turbine. See figure (141).

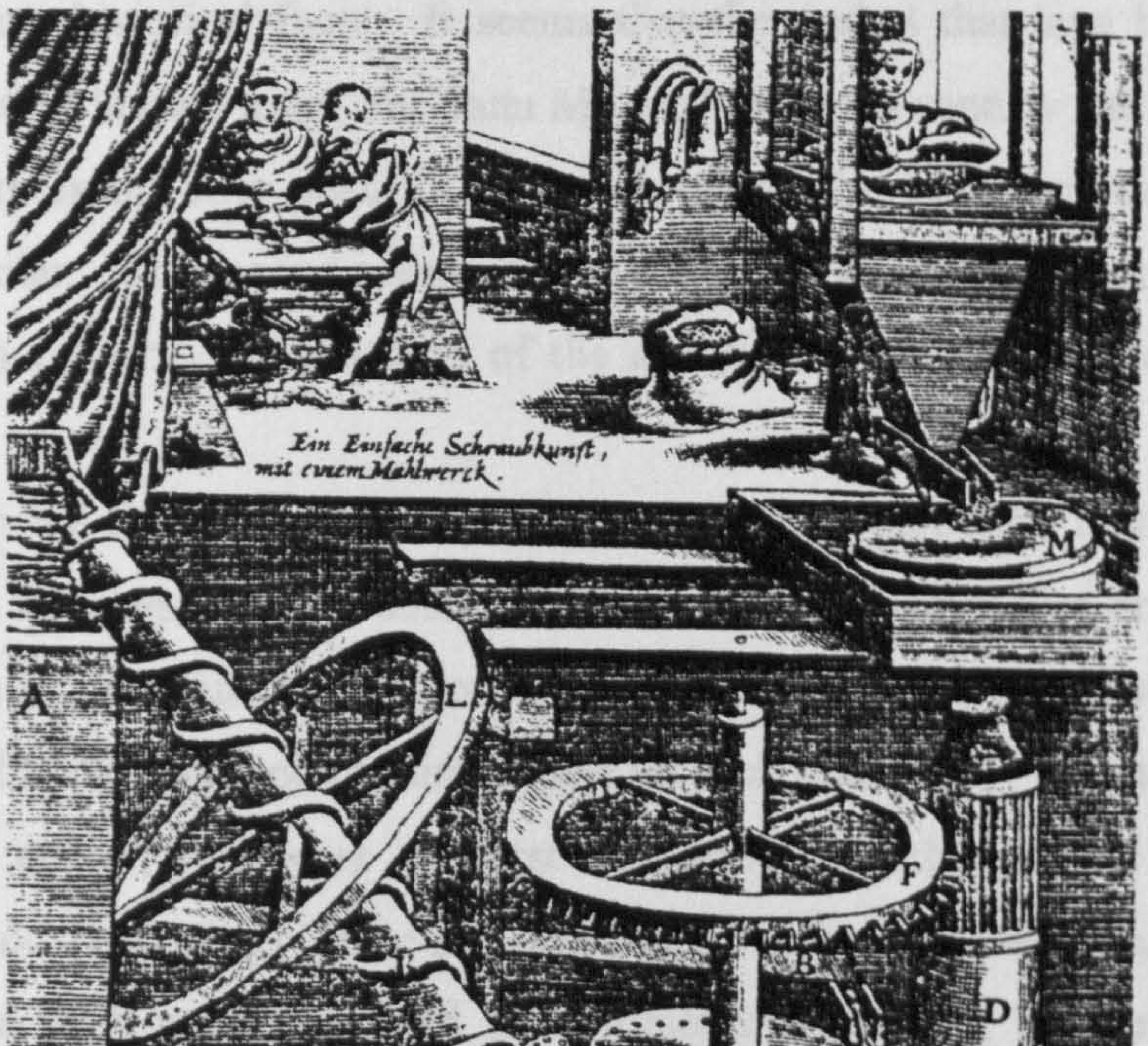


Figure (141)

The self-acting mill, which designed by Georg Andreas Bockler in 1686.

As in the West, perpetual motion in Islam had occupied inventors and the public thoughts for a distinct period in which such concept was a product of certain cultural conditions and circumstances of the time. Unlike the West, in Islam it is extremely difficult to determine a specific period where the interest in perpetual motion was intense and widespread. The absence of dates and authors names from manuscripts makes it difficult to trace any chronological data.

Yet we may assume two possible broad periods, in which the quest for the perpetual motion was more likely, and then introduce a comparison between them according to some historical facts. It seems that the period that lays between the prominent engineers known to us, the Banu Musa of the ninth century and al-Jazari of thirteenth century is the first possible period in which the notion of the perpetual motion was popular. The second assumed period fills the gap between the time of al-Jazari, thirteenth century, and the time of the sixteenth century renowned engineer Taqi al-Din.

Although we find no single date of a machine of perpetual motion type in manuscripts and treatises, and obviously in the work of the Banu Musa and al-Jazari, the transmission of perpetual motion to the West through Islam, which was in early years of the twelfth century, and the first report on such machine by al-Yaqubi in 891 AD, mentioned earlier, reinforces the first assumption. Furthermore, Hill and al-Hassan in 'Islamic Technology' have presumed that the three perpetual machine they reported in their book could be dated back sometimes between the ninth and the twelfth centuries. So it is safe to say that perpetual motion was to a certain extent popular in that period.

Whereas the discovery of the manuscript, I have unearthed, dated in the fifteenth century, which describes a perpetual motion machine supports the second assumption, since it is the only dated document of such machine we posses for the time being. Therefore, any judgement that is based on this only dated manuscript would be insufficient. However, we may look to this historical judgement from another point of view by taking the period in which the perpetual motion attracted the attention of the scientists and engineers in the West, and even their governments. We find this interest was intensified in the seventeenth and eighteenth centuries, in other words between the enlightenment and the industrial revolution eras. So, in a comparative sense, the period between the ninth and the thirteen centuries, which is marked by the supreme power of the Islamic civilisation that witnessed the great translation movement in Baghdad and the scientific development in Andalusia, as a counterparts. Then we may designate this period as the most likely period, in which the interest in the perpetual motion was widespread, as far as the history of Islamic engineering is concerned.

Yet, such assumptions remain inadequate and can not be taken in confidence until serious study and investigation are undertaken covering Islamic engineering in general and the perpetual motion in particular. This task ultimately requires a substantial effort and a long stretch of time.

The Cosmic-Fountain: A contemporary Interpretation

Throughout this study, I have accumulated a wealth of experiences in term of the fountain design and engineering. Thus, the outcome of this experience is reflected in my personal design for a fountain, which I named ' The Cosmic-Fountain', the concept of which is based mainly on three principles. The first principle is to concentrate on a contemporary re-representation of the fountain that produces different shaped emissions to deliver various symbols in water. The second principle is to re-introduce a developed version of medieval-Islamic techniques in constructing a simple and efficient mechanism to generate different shaped emissions from a single fountain body. The third principle is to design a fountain-head from which three different emissions can be produced.

▫ First Concept

The prime idea of the first concept is to design a simple structure that is symbolically representative, functionally efficient and formally artistic. This integrated qualities of the design should appear characteristically contemporary. The fountain is, primarily, intended to be located in the heart of an enclosed courtyard or under a pavilion, where the spectators can experience closer spiritual and aesthetic contacts. Figure 142 shows the idea of the design of the fountain that has the form of an upside-down triangular pyramid. As far as the material is concerned, the design can be produced in different materials such as ceramic, marble, carved stone or fostered-glass. The fountain body is made of three panels, which are held together by means of metal structure.

Through a process of sketching and designing I have end up with the design shown in figure (142). The three triangular surfaces of the upside-down pyramid have the word 'Water' inscribed and engraved in world modern languages as well as some ancient languages, namely Persian, Greek, Chinese, Latin and Arabic. On the background of these words irregular geometric patterns are introduced. See figure 142 and 143.

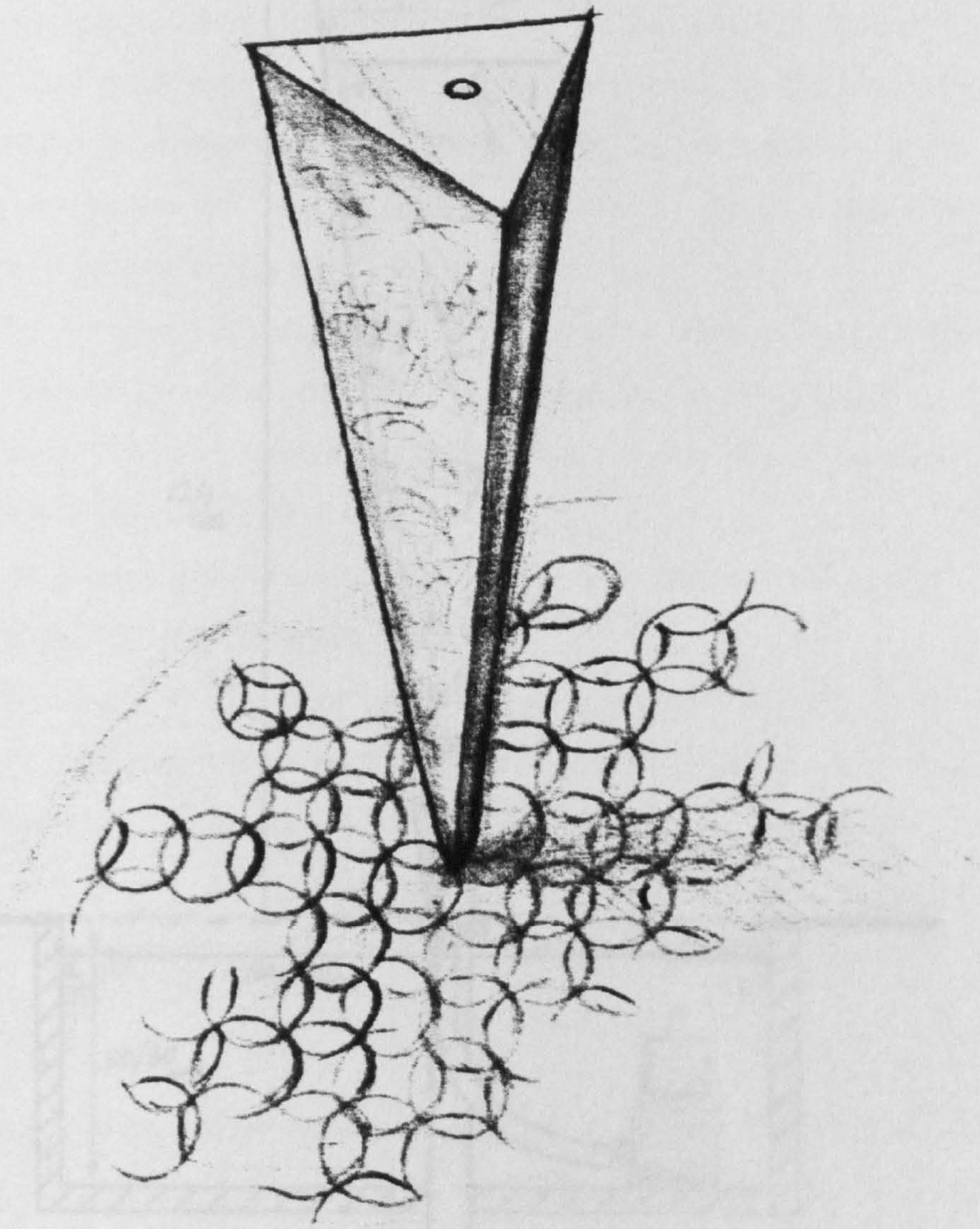


Figure (142)

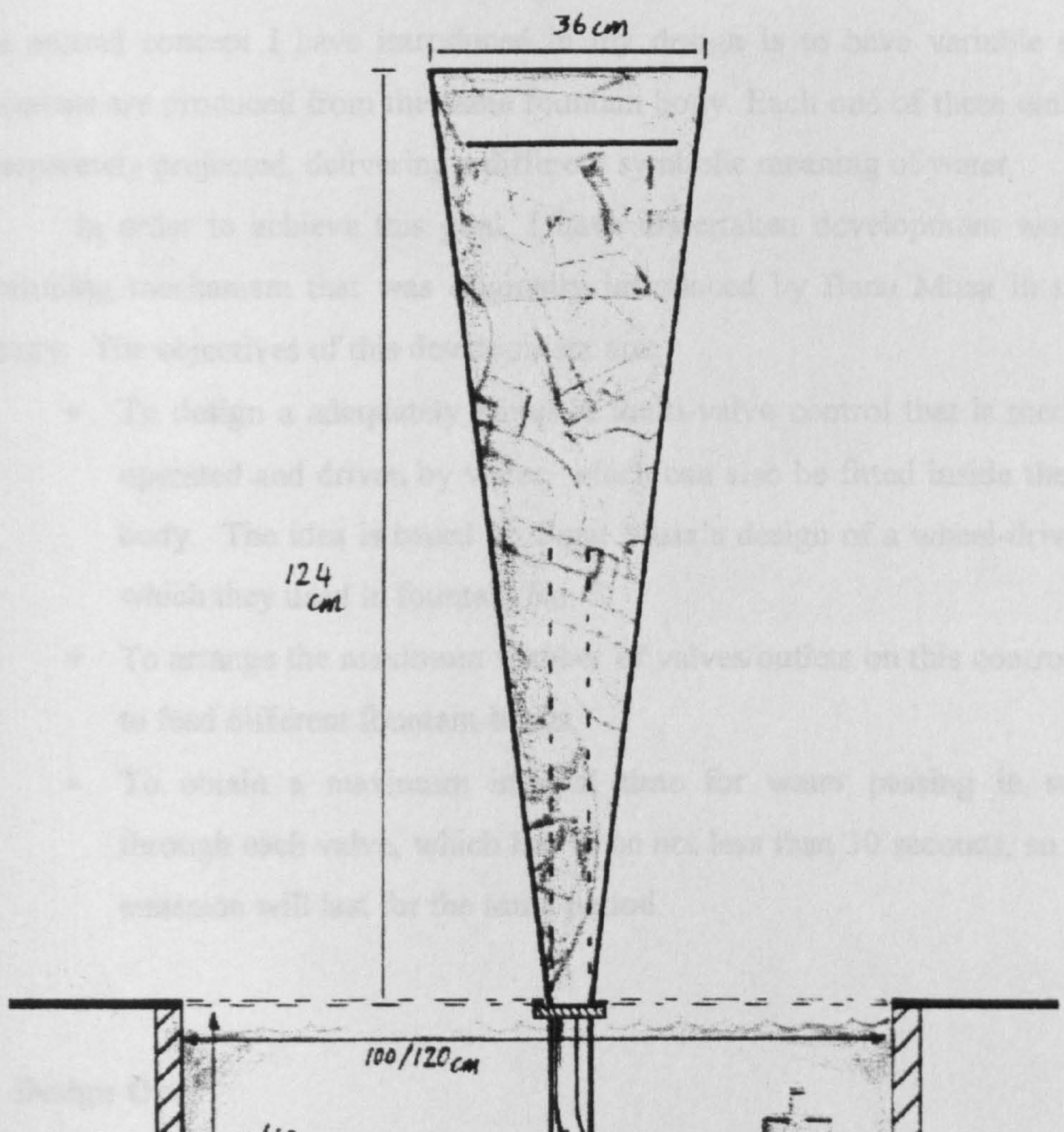


Figure (143)

- <u>**The second concept**</u>

The second concept I have introduced in my design is to have variable shapes of emissions are produced from the same fountain body. Each one of these emissions to be separately projected, delivering a different symbolic meaning of water.

In order to achieve this goal, I have undertaken development work on the controlling mechanism that was originally introduced by Banu Musa in the ninth-century. The objectives of this development are:

- To design a adequately compact multi-valve control that is mechanically operated and driven by water, which can also be fitted inside the fountain body. The idea is based on Banu Musa's design of a wheel-driven valve, which they used in fountain No. 5.
- To arrange the maximum number of valves/outlets on this control in order to feed different fountain-heads.
- To obtain a maximum interval time for water passing in succession through each valve, which has to be not less than 30 seconds, so that each emission will last for the same period.

- **Design One**

The first design of the water control was a development of a number of ideas that were based on the use of a small vaned-wheel/fan to drive the mechanism of the control. Figures 144 and 145 show the actual model of this design I have made, in which the interval time of the water between each valve/outlet was less than a second (this result can also be watched on the video-tape attached). Since the results obtained have been very promising, I have undertaken a radical development step which is introduced in the next design.

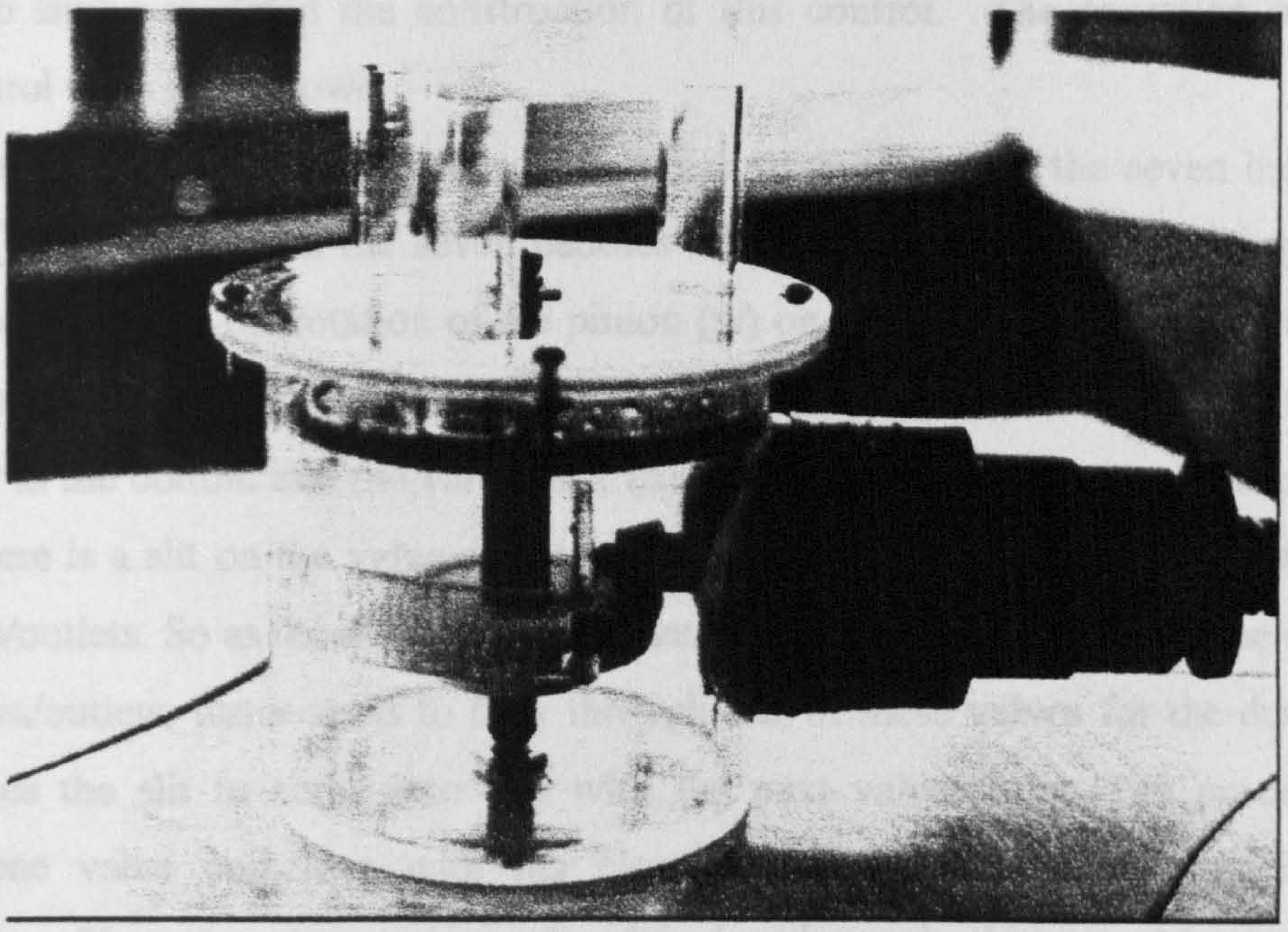


Figure (144)

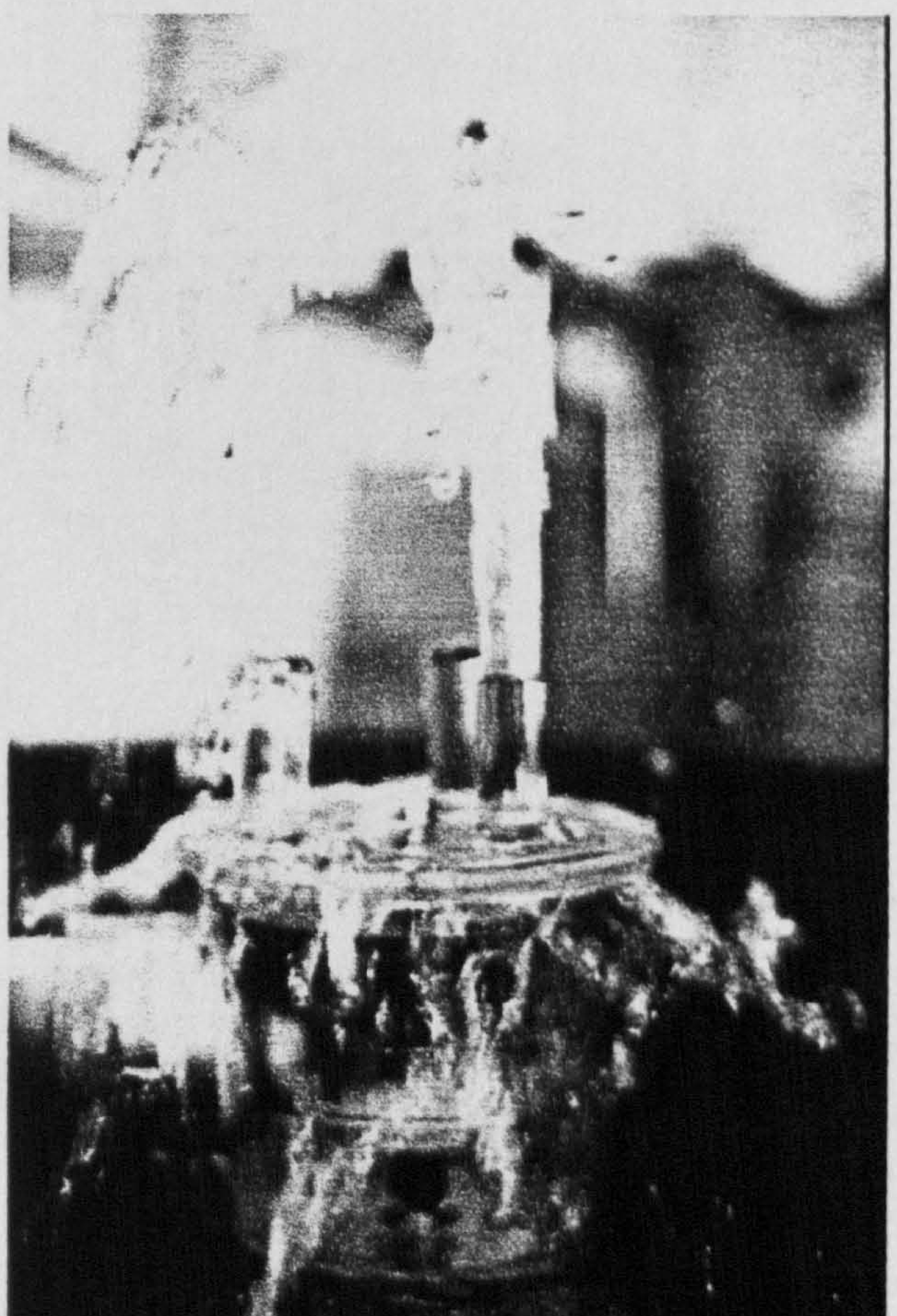


Figure (145)

Figure 146 shows in detail the construction of this control. The operation of this water-control works as follows:

The water is pumped into the inlet, which passes through the seven inclined nozzles (n) that impinge on the seven paddles of the driving-wheel (t), causing it to rotate. Consequently, the rotation of the pinion (w) on the end of the driving-wheel's shaft (f) drives the bevel-gear (b). The transmitting shaft (s) that is connected to the bevel-gear at the bottom and the valve-disk (d) at the top rotates on two pin-bearings (e, e). There is a slit on the valve-disk (v), which stretches for the distance between two valves/outlets. So as the slit (v) on the valve disk (d) comes in line with one of the three valves/outlets, water starts to flow through one of these valves for the duration that it takes the slit to come into line with the next valve/outlet. The process of opening one valve coincides with the closing of the other, so the slit is set accordingly. Since the transmission ratio of the bevel-gear in this experiment was 1: 4, the interval times of water flowing from each nozzle was less than a second.

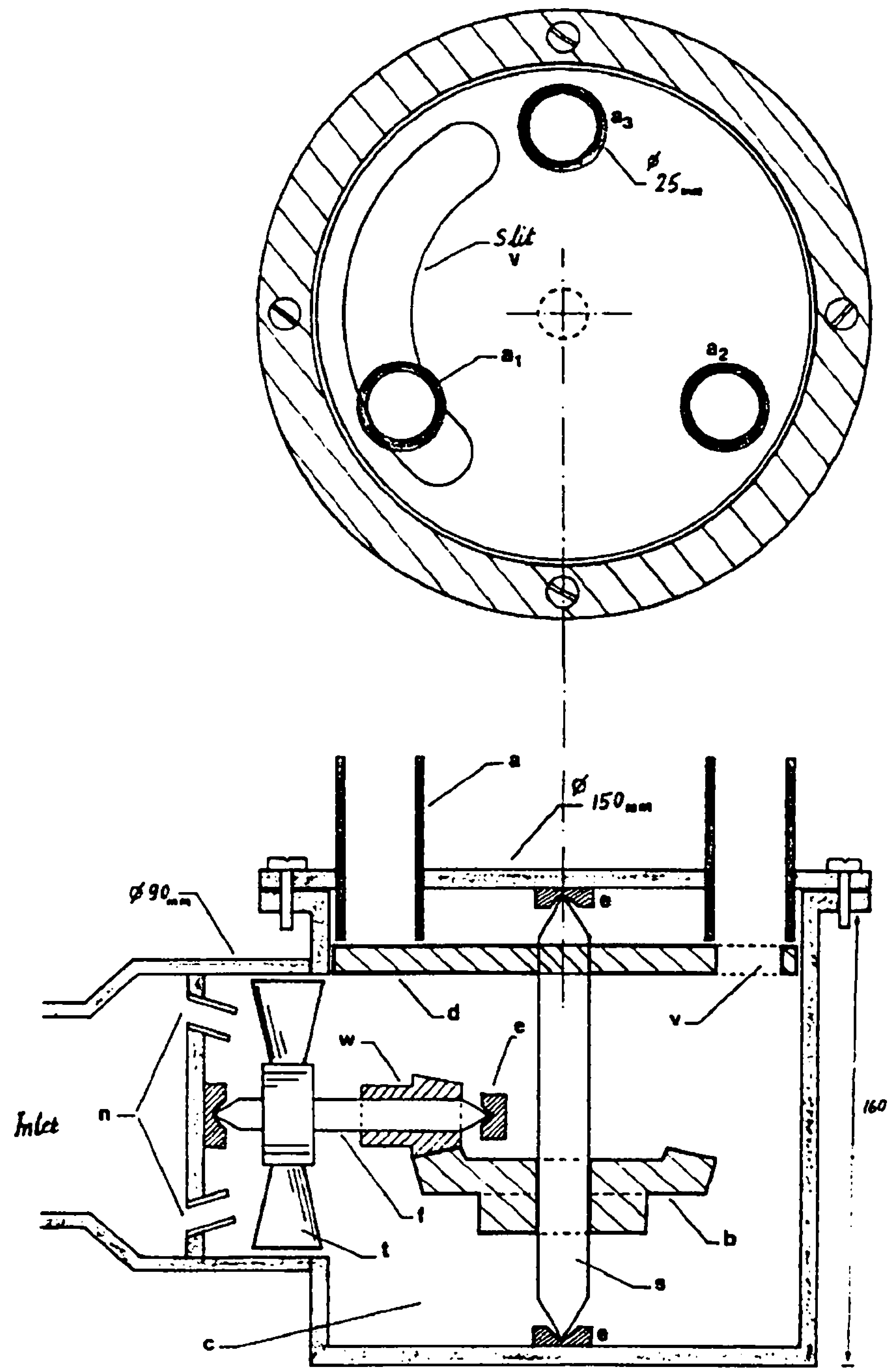


Figure (146). Technical detail of the first multi-valve control.

- **Design Two**

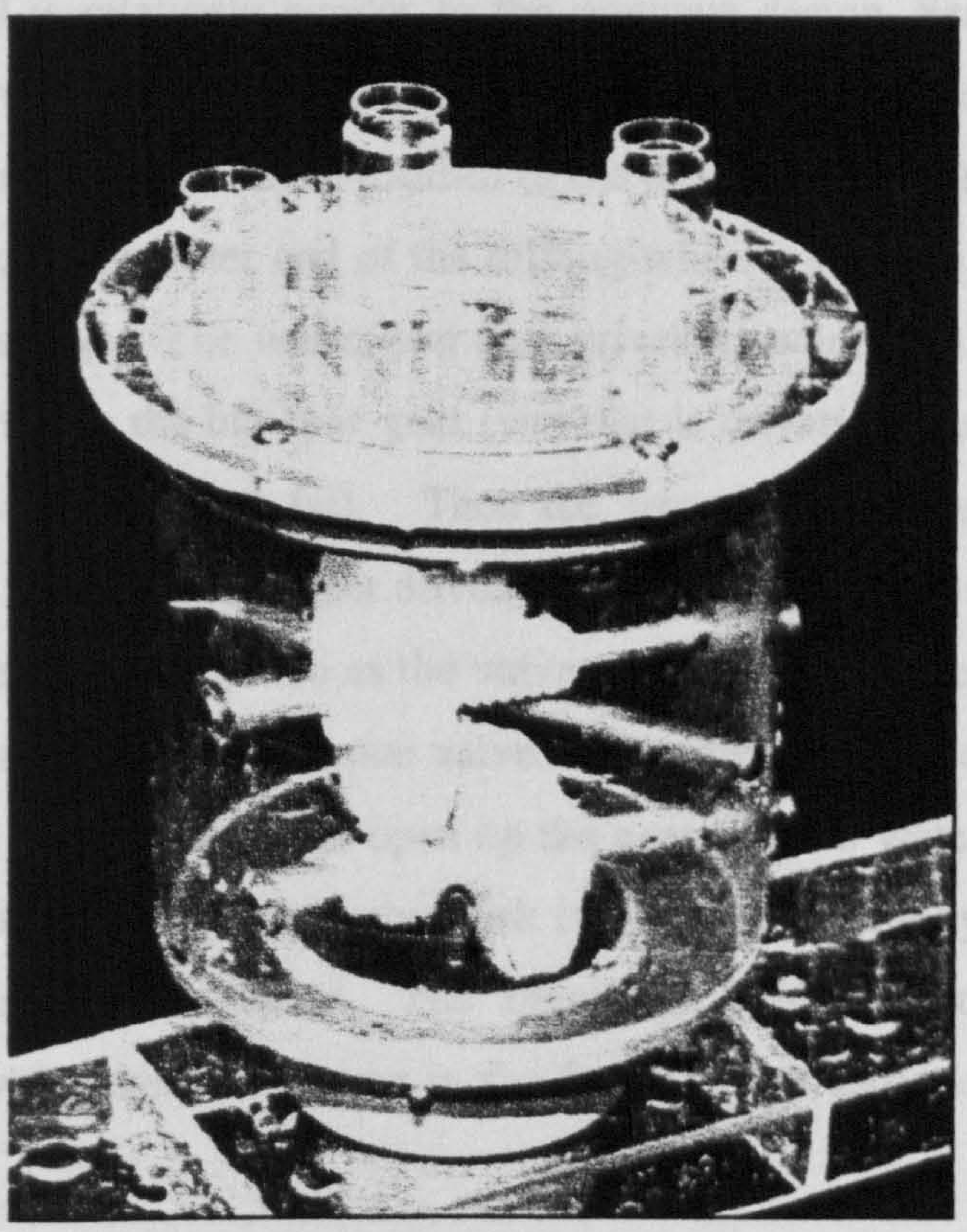
As the first design produced a very promising result, the objectives to be achieved in the second design seemed more challenging. These objectives are mainly based on following points:

- To introduce a huge reduction in the gearing system to provide at least 30 seconds interval time for every change.
- To prevent, as far as possible, any obstruction of the water flowing inside the chamber by the gearing system fitted inside the chamber, which will result in much water turbulence, so creating a significant loss in water pressure.
- To maintain the same size of the chamber that contains the gearing system as in the previous design, with a minimum number of gears.
- To consider the possibility of increasing the number of the valves/outlets to feed more fountain-heads.

Having set the objectives for this second design, I have designed a gearing system that comprises of two worm-gears and two spur-gears. The transmission ratio obtained from this gearing system is (3168:1), which is significantly greater reduction than in the previous design, which was (4:1). As a result of this reduction, the interval time between each valve/outlet is almost one and a half minutes, despite the fact that there are five valves instead of three. This gearing design also minimised the obstruction of the water flow inside the chamber, which is due to the arrangement of the gears in a vertical position. Figures 147 and 148 show my second design of the water control, which worked very successfully. This design is primarily a development of a nine-century mechanism introduced by Banu Musa in their fifth fountain.

The introduction of modern gearing system that provides a highly efficient performance than the basic one of the 9th century, the arrangement of five outlets from one side of the device and the application of new materials has improved significantly the practicality of this control which is also a compact one in comparison to Banu Musa's design by approximately a ratio of 2-4.

Figure 147



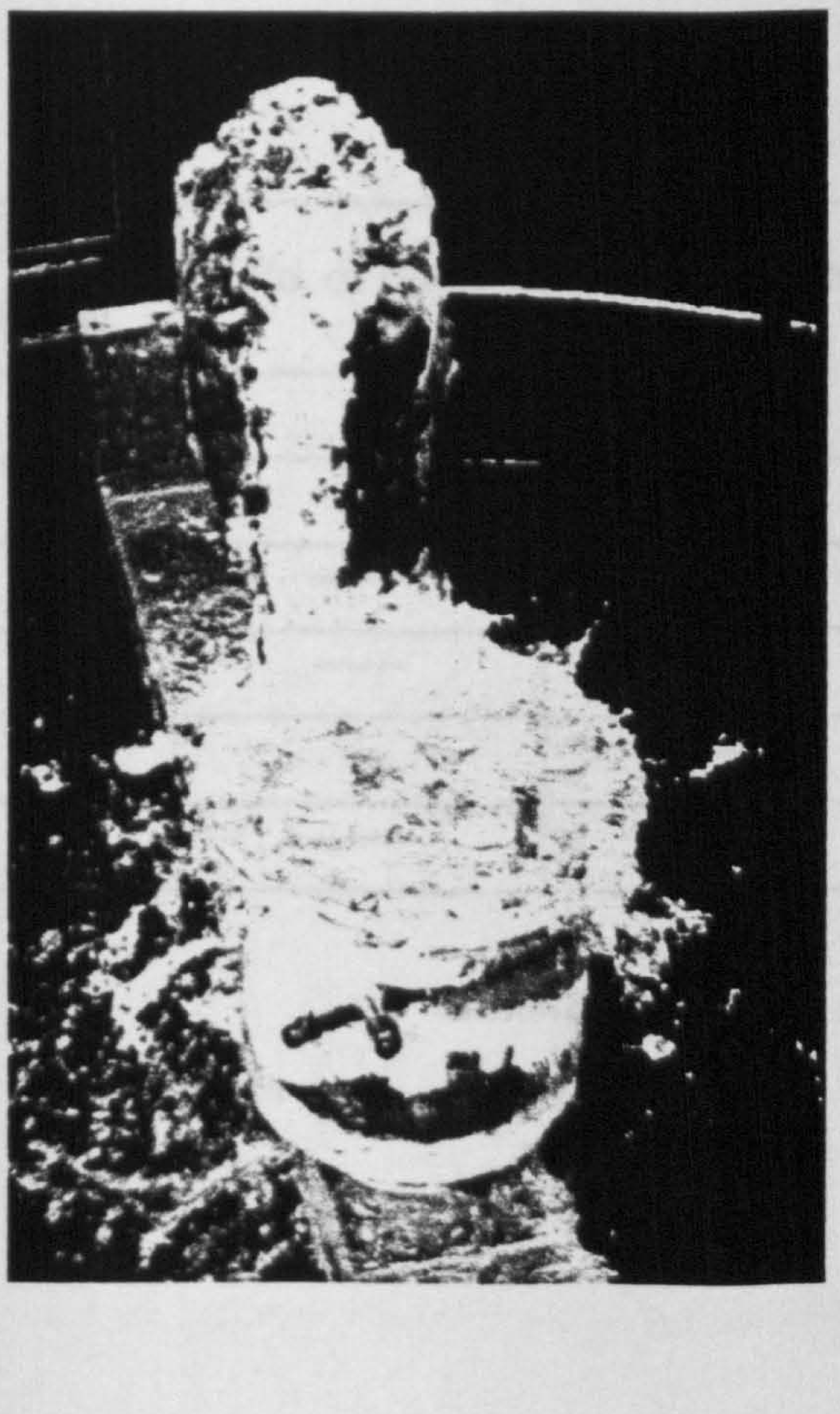


Figure 148

The operation of this water-control is relatively similar to the previous design. See figure 149. The water passes through the seven inclined nozzles (n) positioned beneath the driving-wheel (t) to impinge on the seven paddles of the driving-wheel (t), so the rotation caused is transmitted to the other end of the driving-wheel's shaft (s_1) on which the worm-gear (g_1) is attached. The worm-gear (g_1) drives its wheel (w_1) from which the rotation is transmitted to the big spur gear (w_3) that is driven by the small spur gear (w_2) on the worm-wheel's shaft (s_2). Then the second worm-gear (g_2) that is attached to the shaft (s_3) of the big spur gear drives its wheel (w_4), which is connected to the shaft (s_4) of the valve-disk (d). So as the valve-disk starts to rotate, the curved slit near its edge will come into line with one valve, then water flows into this valve till the slit starts to close up this valve and open up the next one. So water will pass into each valve for the same period as the valve-disk continues to rotate by the force of the water pumped inside the chamber. The alternation between two valves occurs gradually, so as the water starts to die out in the first valve, it starts to emerge from the second one.

Gear & Wheel	No. of starts	No. of teeth	Tooth size	Outer dia.
g1	1	------	1.25mm	------
w1	------	44	1.25mm	55mm
w2	------	16	1.25mm	22.50mm
w3	------	58	1.25mm	75mm
g2	1	------	1.25mm	------
w4	------	20	1.25mm	25mm

Technical detail of the gears and wheels

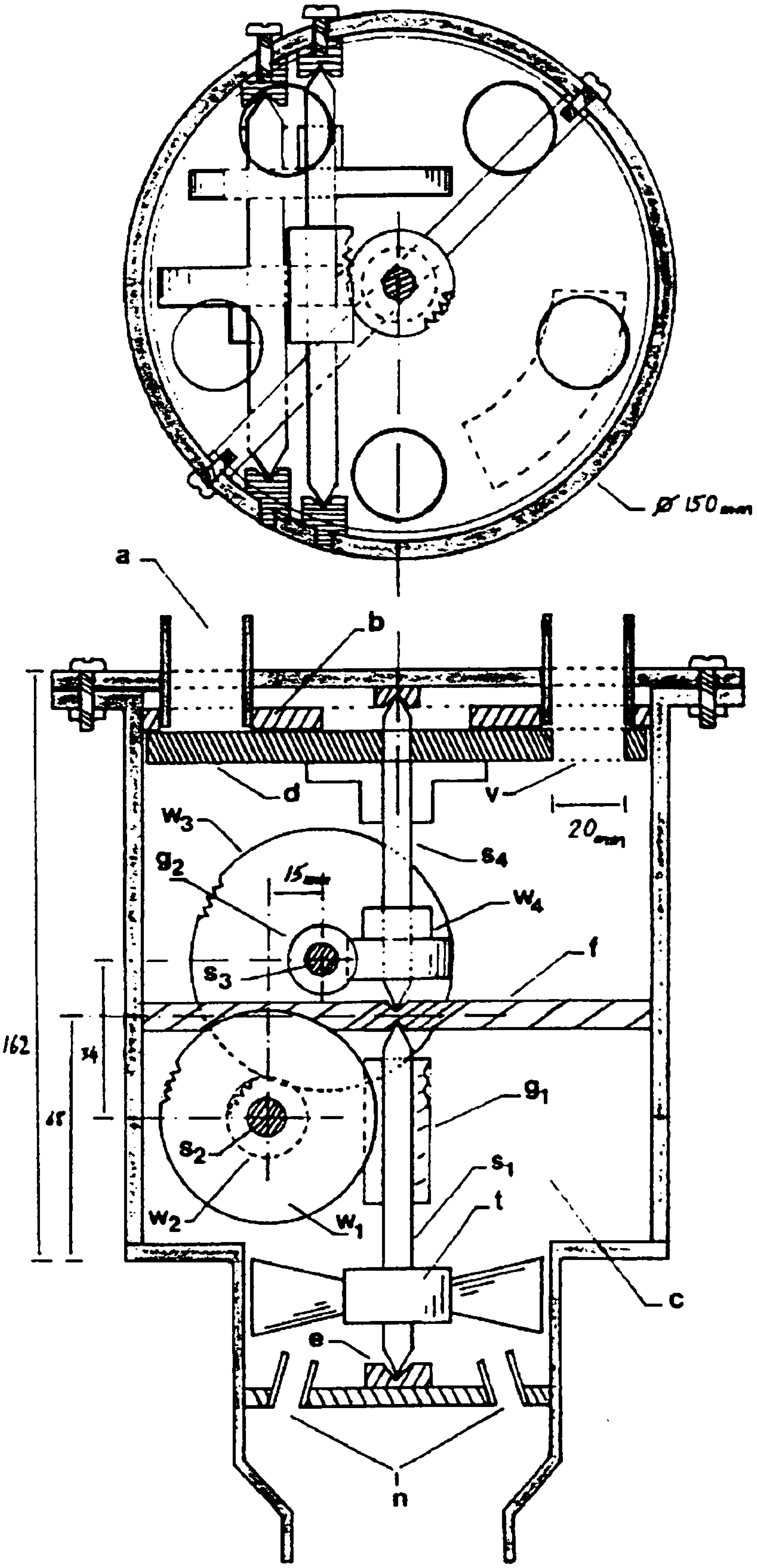


Figure 149. Technical detail of the second multi-valve control.

- ## The Third Concept

Having achieved the design of five-valve water-control, and having done numerous experiments on the fountain-head before, I have designed a fountain-head that produces three different emissions from the same orifice. Figure 150 shows a chamber that is divided into two sections. The top section is covered by the plate that has eight inclined jets, which are to create a swirling motion inside the conical fountain-head placed on top of the jets' plate. Four of these jets are connected to another four jets positioned on the partitioning plate between the two sections. There are two pipes to feed each section of the chamber. The first pipe, with a closed end, passes through the lower section to terminate at the top section. The water passes through two openings on this pipe to feed both sections. The second pipe also passes through the lower section, terminating at the top section to feed the top section. In the middle of this chamber, a narrower pipe passes through the two sections, terminating at the floor of the conic fountain-head. Each pipe is connected to one valve on the water-control. See figure 151.

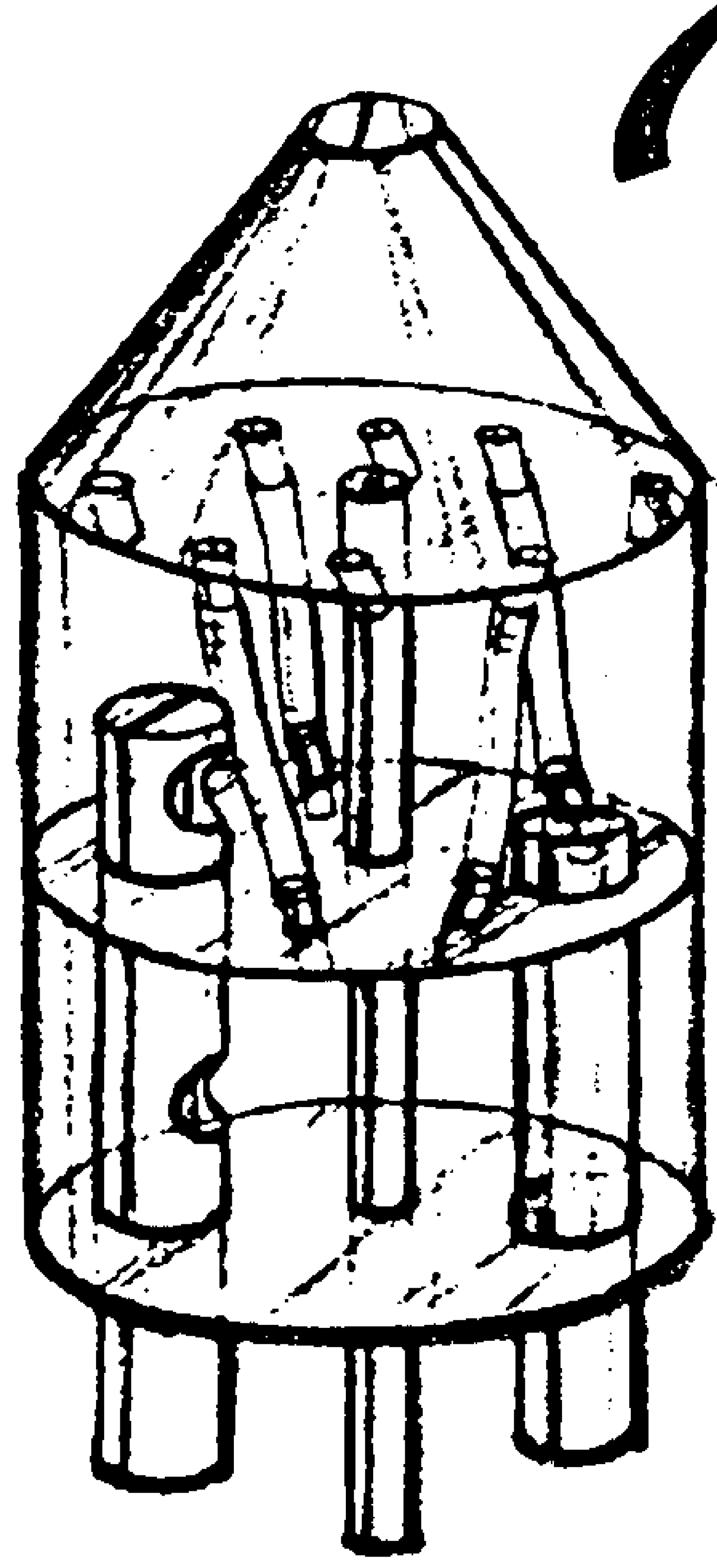


Figure 150

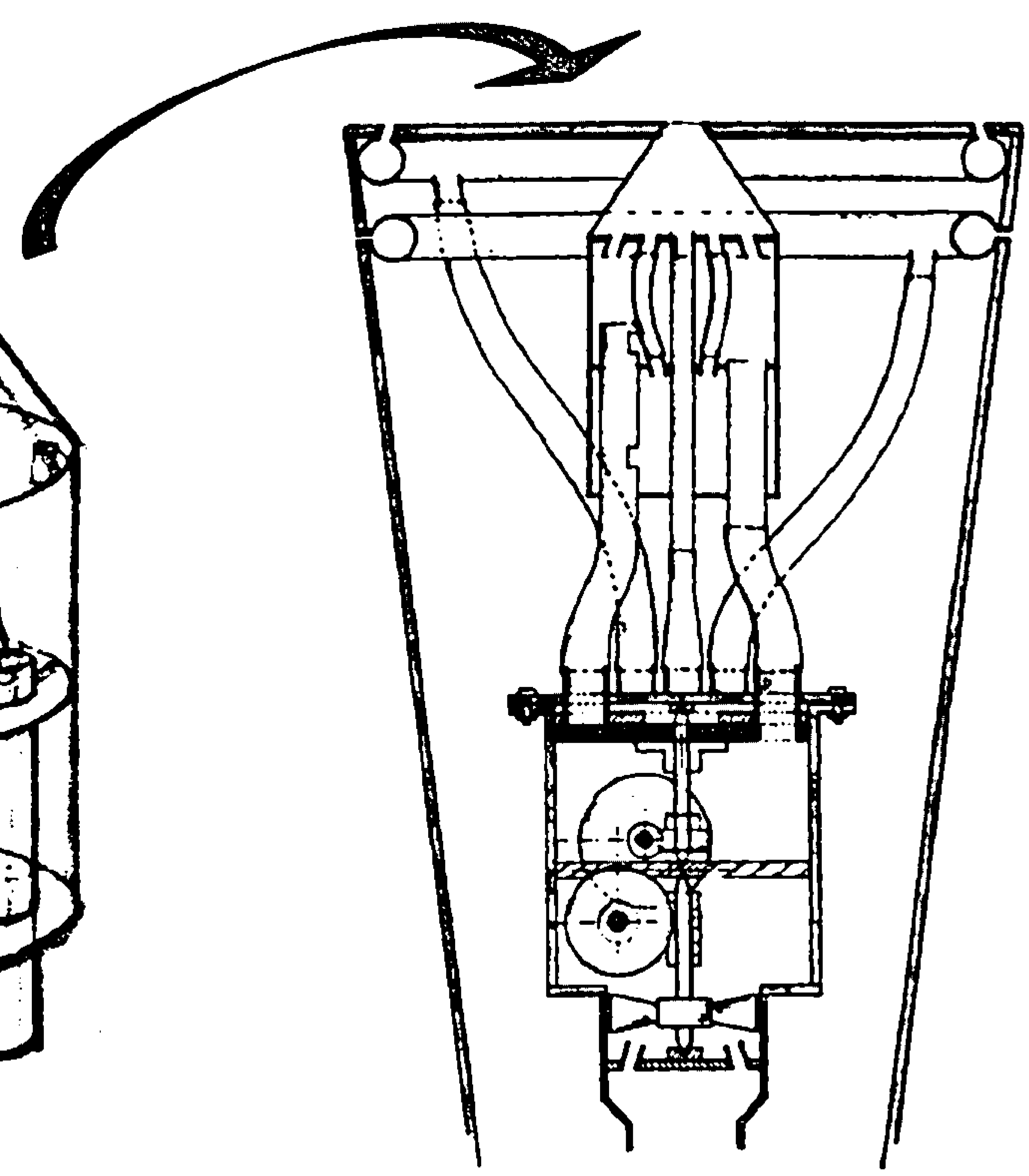
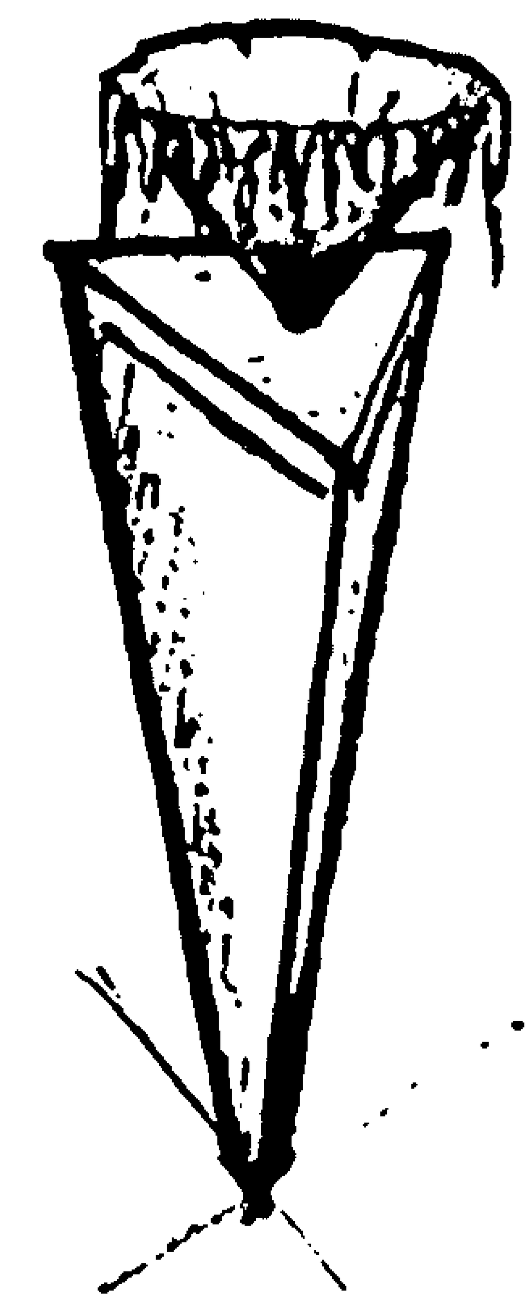
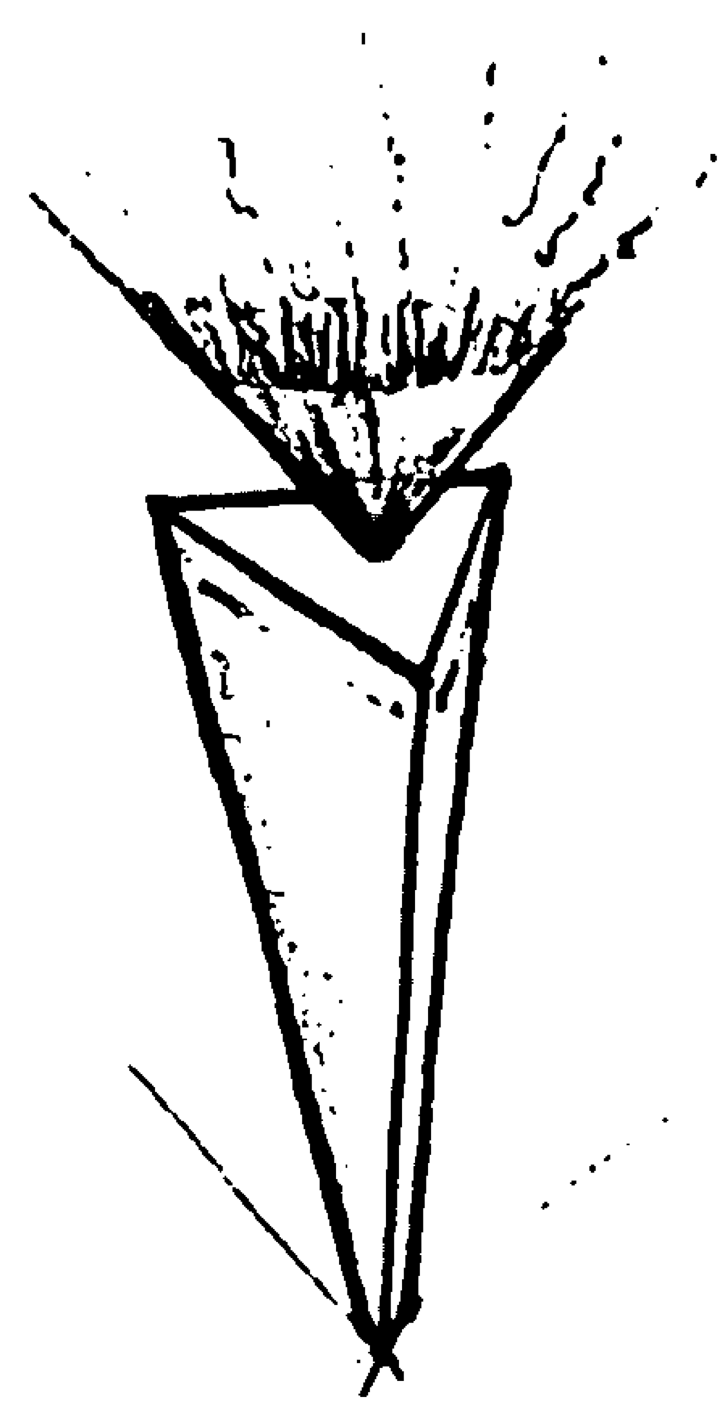


Figure 151

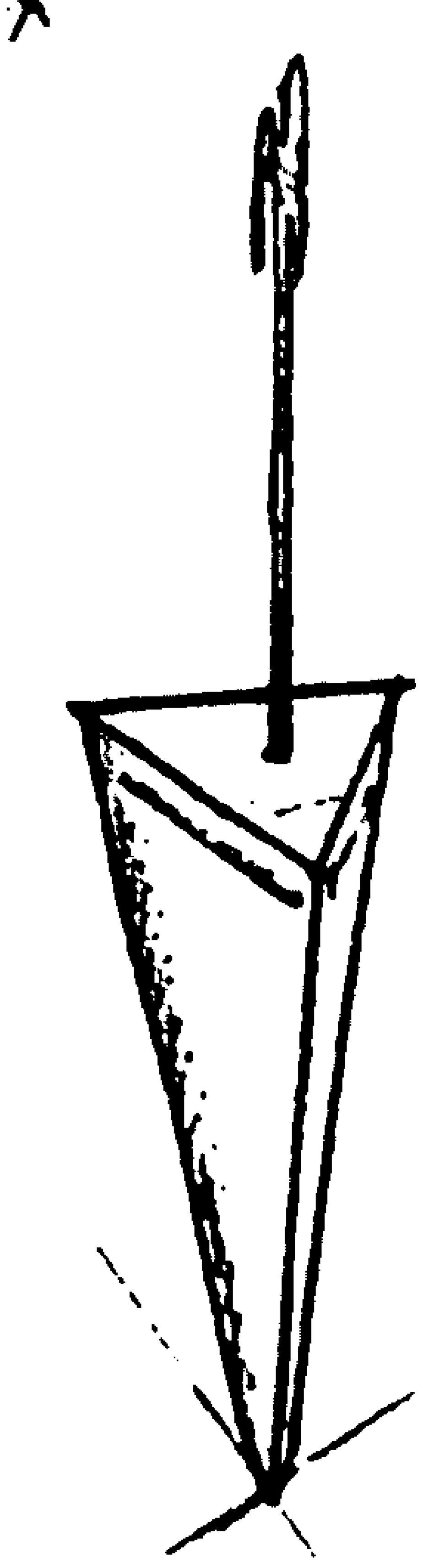
The water released from the first valve on the water-control passes through the first pipe, which injects the water into the sections, so the water will flow into the eight inclined jets at the same time to create a water-cone emission. The symbol that can be attached to the shape of this emission is the 'Spring of Knowledge'. This emission will last for one and a half minutes till the water is directed to the second valve.



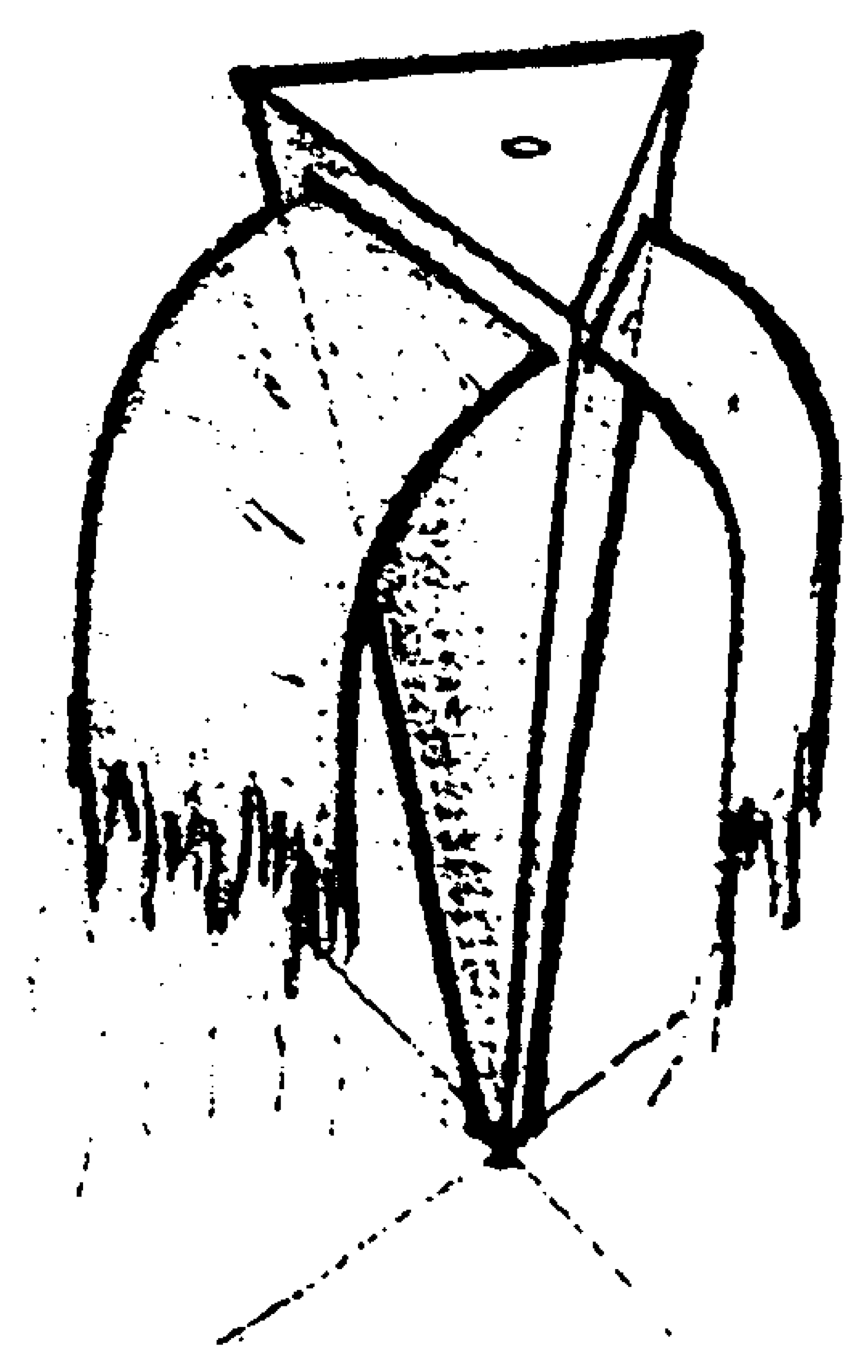
The water will then flow into the second pipe, which deposits the water into the top section, so the water passes only through four jets into the conical fountain-head to create a different water-cone that is wider and higher than the previous one. This emission symbolises 'the spread of knowledge' in all directions.



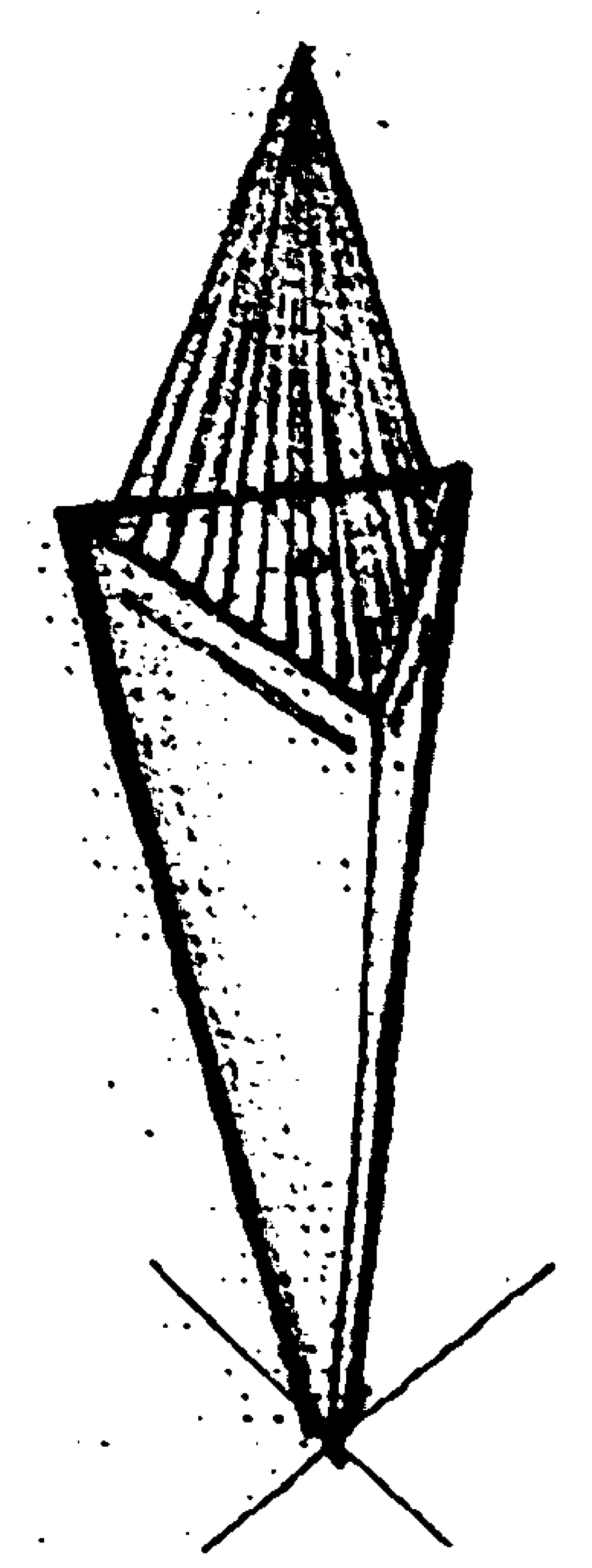
As the emission starts to fade away, after one and a half minutes, the third valve begins to open up, letting the water flow into the narrow pipe from which the water is projected into the air in a single jet through the same orifice. This single jet symbolises the 'Terrestrial axis' that links heaven and earth, and through which the act of descent and ascent of spirit is represented.



The two remaining valves feed the two other fountain-heads. The fourth valve on the water-control is connected to a triangular pipe that has a very narrow opening on each side, so as the water flows into this pipe, three sheets of water then are projected, symbolising the act of equilibrium.



The fifth emission is produced from a small inclined pipe fitted into a triangular pipe at the top of the fountain body. As the water flows into this pipe, released from the fifth valve of the water-control and numerous jets shoot up into the air to meet at one point. This emission completes a diamond shape with the fountain body. It symbolises the water as a 'heavenly diamond' that occupies the heart of everything.



The experimental work of the control mechanism has proven a profound result in achieving this concept. This can be attributed to two points: firstly the arrangement of the five valves on the top of the control, which contributes more efficiently in the smooth flow of water through each valve/outlet in succession. Secondly, the direct connection of each valve with its designated fountain-head. I have tested each emission of this concept separately and have proven ultimate success.

Conclusion

A mortal's soul seems
Like the water,
From heaven coming
To heaven rising
Again renewed then
To earth descending
Ever changing[1].

This study has for the first time identified and assembled a wealth of specific information concerning fountain design in the history of Islamic engineering. Essentially, it has been a practically driven investigation and assessment of fountain designs in the work of the three engineers, Banu Musa[2], al-Jazari and Taqi al-Din, its aims here have been to determine the nature, accuracy and practicality that characterised their designs. Also to examine and assess their engineering potential for and reference to contemporary practice.

Three engineering treatises discovered by the researcher have enriched the investigation carried out through this study. The most important of all is the fifteenth-century manuscript titled 'The Qudsiya Treatise on Constructing a Cascade and a Fountain', *al-Risalaa al-Qudsiya fi Amel al-Shadriwaan wel Fysqiya*, that was previously unpublished or translated prior to this study and describes a perpetual machine to operate a fountain; despite the impracticability of the machine described in this treatise, it is of importance in the history of Islamic engineering.

The second is a section of a fragmented Arabic treatise on engineering in which the drawings of Banu Musa's fountains have supported the researchers arguments on particular fountain designs. The third manuscript is a copy of al-Jazari

[1] From 'A Song of the Spirit over the Water' by GOETHE.
[2] Banu Musa covers in fact the work of three brother engineers but for the purpose of this study are considered together.

treatise, which could have been of great help to Hill and al-Hassan in their editing works of al-Jazari if they had been aware of it. However, it casts a very important light on the history of Islamic engineering as well as giving more credit and publicity to al-Jazari's work.

Perpetual Motion and Perpetuity

This study of the manuscript *al-Risalaa al-Qudsiya fi Amel al-Shadriwaan wel Fysqiya* has identified two new design concepts in Islamic engineering, these are the concepts of portability and miniaturisation. Such concepts have not been reported or even thought of as being used in Islamic design by scholars and historian. This disclosed information is liable to make scholars who deal with Islamic engineering reconsider the prevailing judgement of the design concepts that are usually applied to Islamic engineering. It is conventionally believed that Islamic engineering maintained a consistent tradition in designing devices which may lacked the introduction of radical design concepts. The engineer of this manuscript, however, showed a distinguished originality in his approach to design a small fountain and its machinery that can be easily built and dismantled in a restrict space. This provides clear evidence that such as advanced concept of designing was practised before modern times.

Also new and ingenious ideas of how to operate a machine has been also investigated in the manuscript *al-Risalaa al-Qudsiya fi Amel al-Shadriwaan wel Fysqiya*. The Study of the German scholar Hans Schmeller in 1920 of the perpetual motion in Islamic engineering in many treatises has mainly presented a single concept, which is in a way a continuation of an original Indian idea that was based on gravitational force acting on mercury. Whereas the investigated manuscript has introduced a diverse mechanical concept of designing a perpetual motion machine, which is interestingly connected to a fountain.

The detailed and scientific language that has been translated in this study of the manuscript *al-Risalaa al-Qudsiya fi Amel al-Shadriwaan wel Fysqiya* has provided a new attitude to engineering description that is more advanced than in the work of Banu Musa, al-Jazari and Taqi al-Din. This is clearly presented the lucid and very detailed description of the machine in which some of the physics and mechanical principles involved are explained, this is why it is rather unique in relation to other engineering descriptions. This particular finding may help historians and scholars interested in the history of Islamic engineering in re-evaluating and classifying the status of engineering at the time of manuscript.

The quest for perpetuity has been a consistent theme within the designs of artisans, architects and engineers alike. However, this quest was sought within the spirituality of Islam and presented symbolically. The endless line of a geometric pattern, the ever heart uplifting of the heavenly minarets and the continual fountain's jet shooting into the air resemble the spiritual force behind this quest. This persistent pursuit involving the use of water technology which imbued the spirit of Islam has led Muslim engineers to seek perpetuity in their designs. The water-clock was a constant reminder of the time, as God himself is the Time according to Islamic tradition. The perpetual movement of a water-lifting wheel, *noria,* was an immutable reminder of God's mercy represented by the constant flow of the water over the wheel, this life-giving substance for which thanks were offered. The most exquisite presentation of this perpetuity appeared in the fountain mechanism, the emissions of which symbolise the various manifestations of water. The poetic record of Islamic literature has documented these perceptions in which the sense of continuity as well as the sense of centrality were lavishly expressed.

Fountain Design and Engineering

Water-driven devices were the most distinctive utilising technology in the history of Islamic engineering, although water was the most precious commodity in the land of Islam. The utilisation of water was not just confined to the powering of domestic devices such as the monumental water-clocks like those designed by al-Jazari and the remarkable water pumps designed by al-Jazari and Taqi al-Din. The unprecedented design of fountains' machines was another unique way of utilising water to generate not just mechanical movement but also to serve and reflect spiritual and esthetical values at the highest levels.

The treatises composed by Banu Musa, al-Jazari and Taqi al-Din contain descriptions and drawings that have been copied many times by people who have no engineering knowledge. If they originally functioned as genuine engineering treatises this has been lost[3]. Hill goes even further in analysing the circumstances surrounded al-Jazari's work, he writes:

> "The number of extant (copies) manuscripts, dating from the 13th through to the 19th century, are evidence of the interest taken in al-Jazari's work throughout a large part of the Islamic world. But this interest was not seminal- no-one was moved to take up al-Jazari's ideas and incorporate them in the development of 'useful' machines. The reason for this must lie in historical and sociological causes". (Al-Jazari 3, p. 279)

However, in modern times the lack of clarity in the drawings and descriptions of these fountain designs is also reported in the edited work of the three engineers by Hill and al-Hassan. The poor and basic reproduction of the original drawings and the use of the original descriptive text have made the designs and the mechanisms difficult to understand. The main intention of this study has been to carry out a clear, practically driven investigation; the intended outcome of which has been to yield lucid verifiable descriptions and detailed diagrams of the construction and operation of the fountains. This, in turn has allowed a fuller appreciation of the achievements of these engineers and speculation as to their importance and role in Islam. However once this was achieved a number of other allied points could be made.

The fountain design in the work of these renowned engineers can be ranked in three positions:

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[3] This echoes a similar process in the documentation of practical knowledge in some of the Greek works and also in the West where, for example, the work of French Encyclopaedists in the eighteenth-century resulted in a prime example of a repository of knowledge which nevertheless manages to inform rather than instruct.

First, we may confidently propose that the fountain design in the work of Banu Musa in the ninth-century represents the apogee of Islamic engineering. Although the important innovations of the automatic control based on the conical-valve and the double concentric siphon used in trick vessels, which are in a way an elaborate continuation of Greek works, represents a triumph of engineering, the radical and intricate concepts of fountain design are after all the unprecedented engineering achievements which are totally unique and distinct from the production of the former civilisations. The status of Banu Musa in the history of engineering is not negligible Hill writes:

> "The preoccupation with automatic controls and timing came to be important in the West only in comparatively recent times. There are a number of parallel examples in the history of technology of ideas having lain dormant for centuries, to reappear when the practical need for them arose. This is not to say, however, that the work of the Banu Musa was without influence on the development of Western machine technology in medieval times, but the influence was probably indirect"[4].

The presence of Muslims for almost 800 years on the Iberian peninsula, the European occupancy in the Levant during the Crusading period in the 11th and 12th centuries and the flourishing trade that carried goods far beyond the frontiers of Islamic lands are those streams of cultural contacts between East and West. These are widely discussed by W. Montgomery Watt in his book 'The influence of Islam on Medieval Europe' and in the book 'The Legacy of Islam' edited by Joseph Schacht. In terms of the indirect transmission of engineering Al-Hassan defines more precisely this process, he writes:

> "Technical ideas need not be translated or communicated in writing; they may be transferred from one culture to another by eye-witness. At that time European travellers and tradesmen were frequent visitors to Arab countries.

[4] Hill, Donald (1977) *The Banu Musa and their 'Book of ingenious Devices'*. p. 73.

There were close contacts with craftsmen and artisans, and these travellers examined machines and instruments. Observation and firsthand experience remained the most effective bearers of cultural and civilisation until much later"[5]. (Al-Jazari 2, p. 20)

Second, fountain design in the work of al-Jazari occupied a less important position as his engineering innovation shifted towards water-clock designs. This is why most of the devices used in al-Jazari's fountains, like the tipping-bucket[6], were initially derived from the monumental water-clocks he designed. According to Dahman's investigation there are twenty-one water-clocks which have been reported in different Islamic references, the first of which was erected at the southern-gate of the great mosque in Damascus sometime in second-half of the tenth-century.[7] The most elaborate water-clocks ever documented in Islamic sources are those of al-Jazari. Hill writes:

> "By the 11th century Arabic water-clocks had reached a state of advancement that had no parallel elsewhere. ... It is probable that some of the ideas embodied in the Arabic water-clocks were used in European water-clocks. With the invention of the mechanical clock, relevant Arabic ideas, such as automata, were taken up by European clock-makers. The more delicate mechanisms and concepts entered European technology, by means as yet unknown, when they became necessary for further advances in mechanical technology"[8].

Hill and al-Hassan strongly believe that al-Jazari's treatise is the most important document on mechanics from ancient time until the Renaissance to come from any cultural area.

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[5] Al-Jazari, Ibn al-Razzaz (2) *Al-jami bayn al'il wa l-amal al-Nafi' fi Sina'at al-Hiyal*. p. 20.
[6] The mechanism of the tipping-bucket is clearly shown in the first and second fountain of al-Jazari.
[7] Dhman, M. Ahmad (1985) Ilm al-Sa'at wa al-A'mel biha. p. 36.
[8] Hill, Donald (1981) Arabic Water-clocks. p. 131.

Third, the fountain design in the work of Taqi al-Din occupied a minor status since his engineering works were concerned with time-keeping devices and water-pumps. His writing describes the construction of mechanical clocks like the weight-driven and spring-driven clocks, in which he mentions several mechanisms invented by himself, showing that he had mastered the art of horology.

Thus this study has set a complete design and engineering documentation of the eighteen fountains known in the history of Islamic engineering, which are described by these three engineers. Also it has reinterpreted in detail the drawings of the eighteen fountains, which remained confusing and unclear till the present study. The drawings have been intended to provide a clear presentation of the mechanism of the fountains, so the reader may understand the mechanism and the operation of each fountain without referring to the descriptive text.

Furthermore, this study has been concerned with identifying the example and origin of the three different type of fountain in Islamic architecture; the *Sabil* (drinking-fountain) the *Salsabil* and the *fawaraa* (fountain). This includes a wide discussion of important aspects concerning the philosophy, aesthetics and the architecture of the fountain, which were previously ignored. The only brief study of fountain significance within the architectural context is the paper by Yasser Tabbaa. He writes that his study is: "for the first time a fairly picture of the typology and hydraulic of the medieval Islamic gardens"[9]. Nevertheless this paper lacked a single documentation of fountain engineering or of its underlying philosophy and aesthetics dealing as it did with the typology of Islamic garden.

A unique originality of the mechanisms in the work of the first engineers Banu (sons of) Musa is clearly presented in comparison to the work of their predecessors the Greek engineers Hero of Alexandria and Philo of Byzantium. The Banu Musa's approach was empirical and demonstrates a sophisticated use of mechanics, which take advantage of the mechanical and physics of moving parts. Whereas the works of their predecessors contain more theory than practice and are mainly based on

[9] Tabbaa, Yasser (1992) *The Medieval Islamic Garden: Typology and Hydraulics*. p. 304.

pneumatic principles, which mainly exploit the properties of wind and heat to activate pneumatic mechanism.

This originality is also found in the fountain mechanisms introduced by al-Jazari compared with Banu Musa's fountains, in which al-Jazari designs were diverse. Hill affirms that " Al-Jazari acknowledges the work of the Banu Musa on fountains but in fact makes little use of their ideas in any field"[10]. Yet, the comparison between the mechanisms particularly in fountain design in the work of Taqi al-Din and his predecessor al-Jazari has shown less degree of originality and perhaps can be regarded as a continuation of al-Jazari's work.

Art and Aesthetics

In Islam it is difficult to extract the origin of Islamic art from the juridical sciences and theology, both of which are closely associated with the Divine Law, which defines the relationship between God and man and society on the level of action. Therefore, at one end, for the first time, this study has widely identified the Cosmo-aesthetics of the fountain through an introduction to the philosophy of art, aesthetic, architecture and cosmology of Islam. The significance of fountain in the context of architecture, during the period under discussion, is presented in the notions of unity and centrality, that what comes from the one can lead only back to the one. Also focusing on the fountain within architectural composition, which forms a distinctive typological element in Islamic architecture.

Engineering and Engineers

The ethics of Islamic engineering has been presented through a broad introduction of the direct relationship between the spirituality of Islam and the utility of sciences, that defines the sacredness of science and engineering in Islam. As the outstanding works of Hill and al-Hassan were mainly technically based, any attention to the implication

[10] Banu Musa (1) *The Book of Ingenious Devices*. Edited by Hill. p. 22.

of the ethics of science was absent. The only study that has dealt with the philosophy of science in Islam is by S. H. Nasr (1976) in his book 'Islamic Science: an Illustrated study'. However, the current study is more focused in defining the principles of Islamic mechanical engineering that is derived from the Islamic perspective of realism in classifying knowledge and sciences within the socio-cultural and natural environments.

The supreme practicality of the designs, revealed in this study, represents ultimate examples of Islamic engineering principles and technical abilities. The experimental work that has been undertaken has provided a clear evident of such practicality. Muslim engineers were very clear in emphasising their high craftsmanship as the engineer always starts his description by saying: "I will describe what I have made..." or "I have made...". In comparison these words never expressed by the other anonymous authors who described perpetual motion machines, the author would say "God willing, this will work", "with God's help this will work" or other similar expressions. An example of this is presented in the unearthed manuscript *al-Risalaa al-Qudsiya fi Amel al-Shadriwaan wel Fysqiya*, which has been investigated in this study. We may gather the authors of such impractical machine preferred to disguise themselves since they never described the making of those machines and more importantly because the fact that the concept of ultimate perpetual motion opposes the principles of Islam. Thus, the engineer in Islam was not an academic who set on to introduce possible applications of mathematical process to the solution of problems, which was common among their predecessors, the Greek. The Muslim engineer was as Hill defines:

> "A mechanical engineer is a man who designs and constructs machines of some complexity, which when completed fulfil the function for which they were intended. He should pay due regard to previous practice, and make the best use of the tools and materials at his disposal. Judged by this definition al-Jazari was an engineer, and his book is an engineering document"[11].

[11] Al-Jazari, Ibn al-Razzaz. *The Book of Knowledge of Ingenious Mechanical Devices*. p. 279.

The excellence and sophistication of the mechanisms, on the other hand, were not accidental or a spontaneous outcome of a theory based process. Rather the ingenious designed machines to operate fountains were a production of a process of practical and feedback applications. The application of high level skills and techniques were used to transform ideas and mechanical theories into practical devices. Also through the application of cultural values to enhance the mere practicality of these devices. These were not just associated with their engineering aspect but the esthetical and spiritual aspects were also carefully considered. The book titles of al-Jazari and Taqi al-Din represent a clear indication of these principles. The first book bears the title 'A Compendium on the Theory and Practice of the Mechanical Arts' whereas the later was titled 'The Splendid Methods of the Spiritual Devices'. It is very clear that the originality and genuineness of a fountain design in Islamic history was always connected with the practice of innovative engineering ideas and the practice of the inherent cultural values at the same time. In fact they are mutually supportive, the prestige of cultural importance conferring the freedom to develop through experiment.

The identifiable position of fountain design within a hierarchy of Islamic engineering is an arguable issue. It appears that Muslim engineers dealt with the fountain design as an individual or a special branch of engineering. The supporting evidences of this argument can be identified in a number of points. Firstly, the innovative designs which were unique to the fountain in the works of all engineers. Secondly, the intention of the engineers to devote a separate chapter to fountain design. Thirdly, the immutable architectural significance and spiritual symbolism of the fountain in the culture of Islamic civilisation. Fourthly, it may be associated with the principle of water-power which is perpetual in the sense that nothing is lost.

Efficiency and Practicality

My practical experiments have been conducted from an understanding and interpretation of the original accounts. The study has concentrated on two interesting parts in the fountain's design of Banu Musa's work in the ninth century. These are the design of the fountain-head that produces a water-cone/the shape of the Lily-of-the-valley from a normal orifice, and the design of a water-driven multi-valve control. A great deal of experimentation was required to reconstruct each of the models.

Thus, the principle of adjustment and experiment was a prime characteristic of Islamic engineering. The sophistication and delicacy of water machines requires a great skill to construct and assemble them; these machines clearly could not have been designed originally without a prior series of adjustments and experiments. This in turn created the circumstances that allowed a room for innovation through the testing of new concepts. This is an important condition within a system that relied in the main on the accurate reproduction of previous successors. The process of examination and development of the fountain-head and the multi-valve control undertaken in this study has also stressed this crucial process in perfecting such designs, and has also clearly presented one of the main engineering characteristics that Muslim engineers must have been acquainted with. D. Hill writes:

> "In general, the Banu Musa demonstrate an impressive empirical understanding of their media. We do not know how much they had absorbed from Iranian, Indian and Far Eastern cultures, but we cannot deny their skill nor, in the absence of other evidence, their inventiveness. Aside from any influence they may have had upon engineering posterity, they deserve an honoured place in the records of scientific achievement"[12].

The supreme efficiency and ultimate practicality of the particular components used in fountain design in medieval time have been proven in a contemporary design of fountain introduced in this study. However, the remarkable fountain-head and the multi-valve control, which are adopted in this contemporary design are the sorts of designs that, as this thesis suggests, can be widely used in other fields of water technology for example irrigation systems and environmental projects in today applications as technology that could be significantly developed and used in modern life. Hill informs us with an example of such project that has been undertaken by a

[12] Banu Musa (1) *The Book of Ingenious Devices.* Edited by Hill. p. 24.

research laboratory near Cairo in Egypt on the spiral scoop-wheel. Although this water-wheel raises water to the ground level with a high efficiency, the study has been to improve the shape of the scoop in order to achieve maximum output.

Finally, despite the fact that this study has brought into focus the excellent engineering of the fountain in the history of Islamic civilisation, a vital question seems to remain unanswered. Why there are no obvious influences of such ingenious engineering can be traced outside themselves, even there we possess no single archaeological artefact that might tell us more about the influence of the mechanical engineering of these fountains. Is it because the engineering of the fountain at the time was too specialised? Which meant that the knowledge of which was limited to a particular sector? or were these fountain built in private sites and that is why they were absent from public places? To throw light on these important question marks we must bear in mind that it is not an easy task to determine and identify the direct justifications of rise and decline of fountain engineering and its possible causes. This, in fact, requires a further study of the complex sociological and political circumstances especially during the period from the 9th to the 16th centuries which played a significant part in intellectual life at the time, which is outside the scope of this study. However, a speculative conclusion can be drawn in order to highlight the importance of these historical facts for serious forthcoming studies.

Despite the fact that simple fountains were widely present in both private and public buildings, a presumption that can be introduced here is that the fountain which was linked to a complicated machinery was confined to the buildings of the ruling elites and hierarchies who were generously willing to commission such distinctive fountain. The historical accounts reported in the short study conducted by Yasser Tabbaa, mentioned earlier, may reinforce this argument. The short lived capital of the Abbasid dynasty from 836 to 892, Samarra, is seen as a watershed in the history of Islamic palaces and Gardens, in which the Banu Musa were contemporaries. The largest palaces of this city were the *Jawsaq al-Khaqani* and the *Balkuwra* which contained enclosed spacious courtyards intersected by channels and dotted with magnificent fountains and basins. The ruin of an early thirteenth century Artuqid palace in the citadel of Diyarbakir (southern Turkey) contains the remains of a lavishly built *Salsabil* and high *Shadriwaan*. It is the time when al-Jazari lived and produced his engineering inventions. In comparison the fountain in mosques and ordinary houses was far more modest and never existed in numbers, although there was always a single fountain in the heart of the courtyard of a mosque or a house. Presumably, this is why we possess no historical indication that might tell us about the existence of complicated fountain's machinery even in the surviving medieval mosques. From a theoretical point of view it is right to regard fountain design as a specialised branch of engineering that was promoted by a particular sector for particular application in a particular time.

This study has attempted through a concentration on the practical mechanics of fountain design, to facilitate an understanding and appreciation of their innate qualities as effective devices. Their specialism and cultural isolation perhaps prevented them from exerting the wider influence that their innovation and sheer quality warranted. This dose not mean that despite a gap of over a thousand years that their ideas still relevant and fresh today cannot enjoy both belated recognition and influence.

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Appendix

(a). Reference to contacts with number of institutions in order to gather possible related information on the availability of documentation in a form of manuscript or study covering the Islamic engineering, in particular, water and fountain engineering:

1. **King Abd al-Aziz Library, Medina, Saudi Arabia.**

   This Library is full of collections, mainly dealing with astronomy, the only manuscript in engineering I have discovered is 'Al-Rissala al-Qudsiya fi Amel al-Shedriwaan wal-Fisqiya' (The Qudsiya Treatise on Constructing a Cascade and a fountain).

   Classification No. 8/513 Arif Hikmat Collection.

2. **Oriental and India Office Collection (OIOC), The British Library.**

   The researcher could not find any document relates to the study area in the old catalogues, and unfortunately the new acquisition obtained by OIOC in the last years have not been listed due to financial and time obstacles according to Dr. Barker, the curator of Arabic manuscripts.

3. **The John Rylands University Library, Manchester, UK.**

   The research has resulted in finding an anonymous treatise on pneumatic and hydraulic machines, the writer of which is not identified. The work on mechanics, which is attributed to the Banu Musa, unfortunately breaks in number of places.

   Classification No. Ms 351 [419] section B.

4. **Dar al-Kutub, Cairo, Egypt.**

   After a long research and through a mediator the researcher has been able to obtain a copy of most elaborate engineering manuscript Al-Jami' bayn al'ilm wa l-Amal al-Nafi' fi Sina'at al-Hiyal by al-Jazari, which was copied in 1914.

   Classification No. 37 Sina'a Timur.

5. Spanish Institutions.

The contact with the following institutions has not brought forth any fruit concerning documentation in any form that relate to the area of study:

- **Agencia Espanola De Cooperacion Internacional AEGI, Madrid.**
- **Junta De Andalucia**

  Consejeria De Cultra Patronnato De La Alhambra Y Generalife Granada.
- **Darek Nyumba (Centre for Hispano-Arab and Islamo-Christian research).**

(b). List of classification numbers of the manuscripts that describe perpetual motion machines, which are investigated and examined by Hans Schmeller and Thorkild Schioler. These manuscripts are kept in the library of Leiden in Holland, Oxford in England, Gotha in Germany and Hagia Sophia in Turkey:

- **Leiden Ms. No. 499.**
- **Oxford Ms. No. 954.**
- **Gotha Ms. No. 1348.**
- **Hagia Sophia Ms. No 2755.**